# ECONOMIC WOODS OF THE UNITED STATES

SAMUEL J. RECORD


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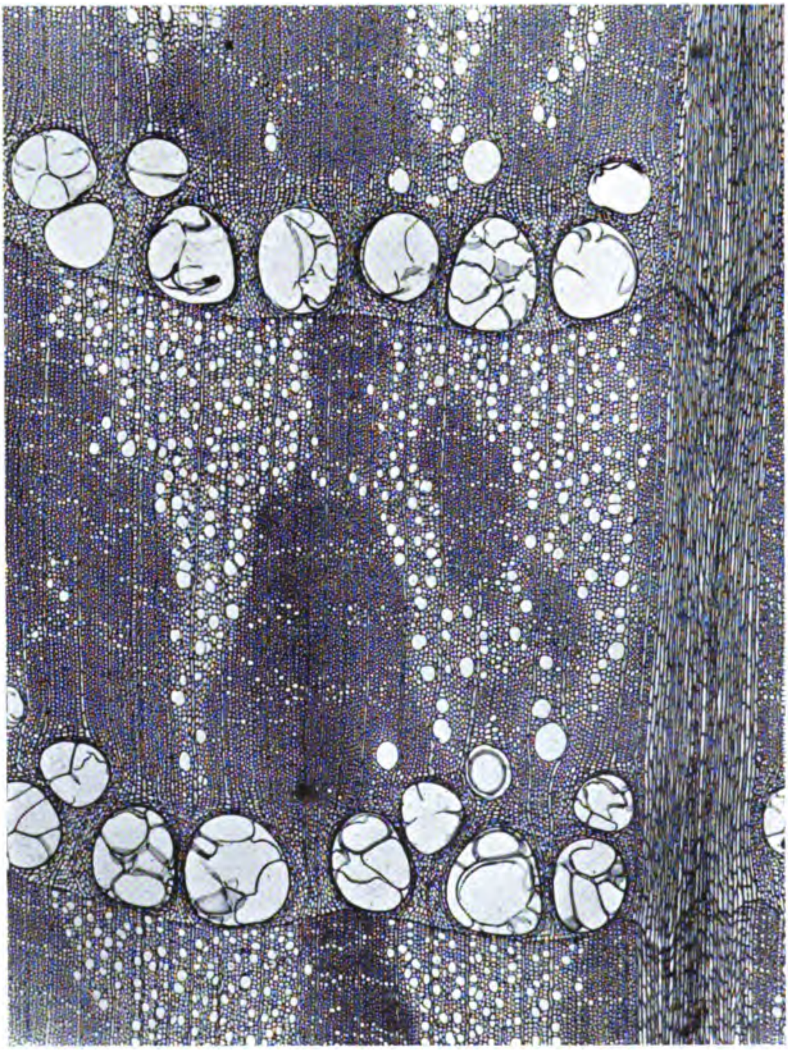

*Quercus alba* (white oak): cross section through one entire growth ring and portions of two others. Note large pores in early wood filled with tyloses and abruptly diminishing in size toward late wood. Small pores thin-walled and in fan-like groups. Note "dipping in" of the outline of the growth ring where it crosses the large ray at the right × 35.

# Identification

OF THE

# Economic Woods of the United States

Including a discussion of the
Structural and Physical
Properties of Wood

BY

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# INTRODUCTION

As the available supply of the standard kinds of timber has decreased, woods have appeared on the market which formerly were considered worthless. In some instances the new woods are sold under their own names, but usually they are employed as substitutes for more expensive kinds, or sold in indiscriminate mixture. It thus becomes a matter of great importance that foresters, timber-inspectors, and wood-users be able to distinguish the woods with which they deal. The number of such woods is so large, and their resemblance often so close, that one can no longer depend upon distinguishing them through mere familiarity with their general appearance. To identify woods it is necessary to have a knowledge of the fundamental differences in their structure upon which the points of distinction are based.

The literature bearing directly upon this subject is very limited, and such information as exists is for the most part distributed throughout a considerable number of publications and not readily available. Teachers and students of wood technology are seriously handicapped by the lack of suitable text-books or manuals. It is in an attempt to supply in small part this deficiency that the writer has prepared for publication a portion of the material given in one of his courses in Forest Products at the Yale Forest School. While it is designed primarily as a manual for forestry students, it is hoped that it will also aid others in the study and identification of wood.

Part I deals briefly with the more important structural and physical properties of wood. The structural properties are based upon the character and arrangement of the wood elements. Under this head are considered: (*a*) the external form of the tree in its various parts; (*b*) the anatomy of the wood; (*c*) abnormal developments or formations; (*d*) relation of these properties to the usefulness of wood; and (*e*) their importance in classification. The physical properties are based upon the molecular composition of the wood elements. Under this head attention is given to (*a*) the properties manifest to unaided senses, viz., color, gloss,

odor, taste, and resonance; (*b*) those determined by measurement, viz., density, weight, water content, shrinkage, swelling, warping, and hygroscopicity; (*c*) relation of these properties to the usefulness of wood; and (*d*) their employment to some extent as aids to identification.

In Part II attempt is made to use the details of Part I in the construction of an artificial classification of the economic woods of the United States. Unimportant species have in some cases been included where it was felt that their presence would not lead to confusion. This classification has been prepared with two objects in view: (1) for use in practice as a key for the identification of unknown specimens; (2) for use in the laboratory as a basis for the comparative study of known specimens.

As far as considered practicable, the distinctions in the key are based on macroscopic features, those readily visible to the unaided eye or with the aid of a simple lens magnifying 10 to 15 times. Owing to the great variation of wood it is usually unwise to rely upon single diagnostic features, and for this reason the descriptions have been extended to embrace all or most of the important characters so far recognized. This method also permits ready rearrangement of the key or the fitting into it of additional woods.

In the woods of many genera the structural variations apparently are not sufficiently distinct and constant to assure specific identification. Good examples of this are afforded by the woods of *Pinus*, *Quercus*, *Hicoria*, and *Populus*, where it is usually difficult and very often impossible to do more than separate them into groups. Accurate knowledge of the botanical and commercial range of each species will often serve as a basis for further subdivision of a group in which other distinctions are apparently wanting.

In preparing a specimen for careful examination either with or without a lens it is highly desirable that a very smoothly cut surface be obtained. If the knife used is not sharp, the cut surface will be rough and the details of structure obscured. Cross sections are, as a rule, the most valuable for comparative study, and in making them it is very important that the plane of section be as nearly as possible at right angles to the vertical axis of the specimen.

A compound microscope is necessary for the study of the minute anatomy of wood. Sections for immediate observation

may be cut free-hand with a sharp pocket-knife or razor and mounted in water. To avoid air bubbles in the sections small pieces of the specimens should be boiled prior to sectioning. It is not important that such sections be of uniform thickness, since a thin edge will usually exhibit the essential details.

Much better results can be obtained by the use of a microtome. Penhallow recommends a table microtome and a plane blade mounted in a heavy wooden handle of such a form as to provide a perfectly firm grip. For fine work, however, a sliding microtome specially constructed for sectioning wood is best. Success depends largely upon the sharpness of the knife and the rigidity of the apparatus.

Considerable care should be exercised in the selection of material for sectioning. Small blocks of about a quarter-inch cube should be cut from green material, or from the interior of dry pieces. The faces of the blocks should represent sections which are as nearly cross, radial, and tangential as possible. Blocks of the lighter woods can be softened sufficiently by boiling them in water until thoroughly saturated. The process may be hastened by interrupting the boiling by additions of cold water. In the case of the harder woods, however, it is a good plan to place the small blocks, after boiling, in a solution of hydrofluoric acid for a period varying from ten days to three weeks, the strength of solution and the duration of immersion depending upon the hardness of the wood. After removal from the acid the blocks should be thoroughly washed and then placed for several days in glycerine, after which they are ready for sectioning. The sections may either be mounted unstained in glycerine or stained in the usual way and mounted in balsam. For ordinary work unstained glycerine-mounts afford the most satisfactory results, since the natural colors are preserved. (For more detail, see references below.)

*References*

Bailey, I. W.: Microtechnique for Woody Structures, Bot. Gaz., Vol. XLIX, Jan. 1910, pp. 57–58.

Plowman, A. B.: The Celloiden Method with Hard Tissues, Bot. Gaz., Vol. XXXVII, June 1904, pp. 456–461.

Penhallow, D. P.: North American Gymnosperms, Boston, 1907, pp. 16–23.

Benedict, H. M.: An Imbedding Medium for Brittle or Woody Tissues, Bot. Gaz., Vol. LII, Sept. 1911, p. 232.

Thompson, R. B.: A Modification of a Jung-Thoma Sliding Microtome for Cutting Wood, Bot. Gaz., Vol. L, Aug. 1910, pp. 148–149.

The best idea of the form and size of the individual cells is gained from studying macerated material. This is readily obtained by placing small pieces of wood in a test-tube together with a number of crystals of potassium chlorate, and adding enough nitric acid to cover them well. After the wood has turned white the solution should then be poured off and the material washed thoroughly in water. This action may be hastened by warming. It is then easy to remove a small portion of the mass to a slide where it can be dissected with a couple of needles and studied under the microscope.

The writer desires to acknowledge his indebtedness to Prof. James W. Toumey for much of the data upon which this work is based; to Mr. Clayton D. Mell for many helpful suggestions and criticisms; and to Mr. Charles J. Heller for the loan of a set of wood sections from which the photo-micrographs were made by the writer at the Forest Products Laboratory, Madison, Wisconsin.

# PART I

# STRUCTURAL AND PHYSICAL PROPERTIES OF WOOD

## GENERAL

Wood of a timber-producing tree may be considered under three general heads, viz., *root, stem,* and *branch.* The relative proportion of the three classes of wood in a tree depends on the species, the age, and the environmental conditions of growth. The woody portion of stem and branch has, within certain limits, the same structure. Branches are of less technical value because of their irregular shape and small dimensions. The latter is due to the fact that the number and thickness of the layers of growth are less and the wood elements smaller than in the bole.

Wood of roots always differs somewhat from that of the stem in form, structure, and distribution of the elements; the growth rings are narrower, the elements have wider lumina, and the wood is as a rule lighter, softer, and more porous. Roots, with occasional exceptions, are a very subordinate source of wood in America.

Stem wood, on account of its more desirable dimensions and shape and its greater uniformity, is of the greatest utility and value. The form and character of the stem are of greater importance than the relative volume; with few exceptions the more nearly straight and cylindrical and the freer from limbs, knots, and defects, the greater are its technical properties and value. These properties are largely determined by the age of the tree and the inherent characteristics of the species, though affected by environment. Straightness and clearness are materially influenced by density of stand.

A woody stem, branch, or root is composed of three unlike parts (Fig. 1). Through the central portion runs a narrow cylinder of soft tissue, the *pith.* On the outside is *bark.* Between these two and making up the bulk of the structure is the *wood* or *xylem.* The wood, particularly in old sections, usually shows a central

colored portion, the *heartwood*, and a nearly colorless outer border, the *sapwood*. In fresh-cut green sections the sapwood is further differentiated by its greater moisture content.

Indigenous arborescent plants are readily separable into two

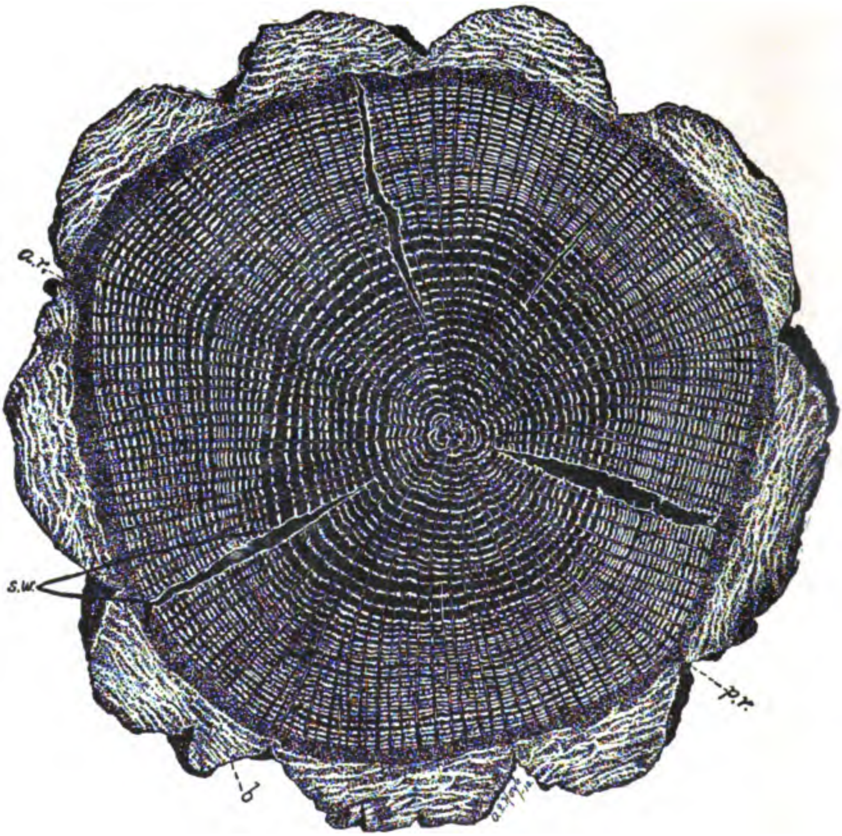


**Fig. 1.—Cross section of stem of *Quercus prinus* (chestnut oak); *b*, bark showing outer and inner portions; *s. w.*, sapwood: the darker inner portion is heartwood; *a. r.*, annual or growth ring; *p. r.*, (pith) ray, a large number of which can be seen crossing the growth rings at right angles. Note season checks. Natural size. (From Bul. 102, U. S. Forest Service.)**

great natural classes: I, Gymnosperms, and II, Angiosperms. Class I is further divided into two unequal groups: *Coniferæ* (13 genera), and *Taxaceæ* (2 genera). Class II embraces (according to

Sargent's "Manual of the Trees of North America"), Monocotyledons (2 families and 8 genera), and Dicotyledons (57 families and 149 genera). The Monocotyledons are of comparatively slight importance as sources of wood, and for that reason, as well as on account of their peculiar structure,* are omitted from the general discussion of wood and from the key.

The woods of the Gymnosperms are commonly referred to as "coniferous woods," "softwoods," and "needle-leaved woods." These terms are inexact since (1) the *Taxaceæ* do not bear cones; (2) many of the so-called "softwoods" (*e.g.*, *Pinus palustris*, *Pseudotsuga*, *Taxus*) are harder than many of the so-called "hard woods" (*e.g.*, *Populus*, *Salix*, *Æsculus*, *Tilia*); and (3) the contrast in the leaves is by no means always as great as the terms "needle" and "broad" would indicate. Common usage, however, has given these names sufficient definiteness for ordinary purposes, though they should be avoided where scientific exactness is desired.

## PITH

The central portion of the young shoot, branch, and root is composed of loosely aggregated, mostly thin-walled, isodiametric, parenchymatous cells—the *pith*. It is usually of small diameter, does not increase in size after the first year, in fact, may even in some instances be compressed, and appears to be of only temporary utility to the tree. In some cases, according to Gris (*loc. cit.*), the cells remain active for several years, and alternately store and give up products of assimilation, especially starch and tannin, according to the periods of vegetation. In such instances the walls of the active cells are thickened and densely pitted.

The pith in woody stems of Gymnosperms is fairly uniform in shape, size, color, and structure; in Dicotyledons there is great variation. As to outline in cross section: it is star-shaped in *Quercus*, triangular in *Fagus*, *Betula*, and *Alnus;* ovoid in *Tilia*, *Fraxinus*, and *Acer;* circular in *Juglans*, *Ulmus*, and *Cornus*. In *Juglans* the color is black; in *Gymnocladus* it is red; in many others it is brown or gray. In *Rhus*, *Sambucus*, and *Ailanthus* the

* In adult stems of Monocotyledons the fibro-vascular bundles are scattered throughout the central cylinder instead of being disposed in a circle, as in the Dicotyledons. The bundles are closed and the tracheary tissue surrounds the phloem.

pith is comparatively large and conspicuous, often deeply colored. In *Magnolia*, *Liriodendron*, *Nyssa*, *Asimina*, and *Anona* there is often a more or less distinct septation of the continuous pith by plates of stone cells, while in *Juglans* there is decided septation but the diaphragms are not sclerotic, and the pith is not continuous between the disks. On account of these and other peculiarities the pith when present in a specimen of wood is frequently an aid to identification.

*References*

DEBARY, A.: Comparative Anatomy, Oxford, 1884, pp. 402–403; 533–534.

FOXWORTHY, J. W.: Discoid Pith in Woody Plants, Proc. Indiana Academy of Science for 1903, Indianapolis, 1904, pp. 191–194.

SOLEREDER, HANS: Systematic Anatomy of the Dicotyledons, Oxford, 1908, pp. 133–134.

GRIS, A.: Sur la Moelle des Plantes Ligneuses, Amer. Sci. Nat., Sér. 5, Tome XIV, 1872.

## BARK

*Bark* is the name commonly applied to that portion of a stem lying outside the cambium layer. Used in this broad sense, it is customary to distinguish an *outer* (dry) portion and an *inner* (living) portion. The structure of bark is highly complex and widely variable.

When shoots are first formed they are covered by a very thin layer of tissue, the *epidermis*. Beneath this is the *primary cortex* and the *pericycle*. The latter is commonly composed of two kinds of tissues, *thin-walled parenchyma* and *bast-fibres*. The bast-fibres may occur in isolated groups or form a continuous band around the stem. When in groups they are often closely associated with, but not really part of, the phloem of the vascular bundles. Bast-fibres are attenuated sclerenchymatous elements, with sharp ends simple or branched. Their function is to give strength to the stem and to protect the delicate tissues of the phloem. It is to them that many barks owe their great toughness and pliability.

*Phloem*, which is the outer portion of a *vascular bundle*, is in typical cases composed of *sieve tubes*, *companion cells*, and *phloem parenchyma*. In structure sieve tubes resemble vessels, but their walls are mostly delicate, non-lignified, colorless, cellulose mem-

branes. Between the ends of the sieve-tube segments (and sometimes between adjacent side walls as well) are thin plates dotted with pits, resembling a sieve. The pit membranes are finally absorbed, allowing free communication from one cell to another. Unlike vessels, the segments of the sieve tubes remain alive for a year or more, though they lose their nuclei. This unusual phenomenon may be due to some influence of the companion-cells which are always so closely associated. The function of the sieve tubes is the vertical (especially downward) distribution of elaborated food materials. After the first year the cells usually become crushed by the pressure of the surrounding tissues, their places being taken by new cells generated by the cambium.

In addition to the structure just mentioned, many other elements and structures may enter the composition of the bark. Among these may be mentioned *resin ducts, latex tubes, stone cells, crystals, mucilage sacs,* and *tannin sacs. Bast rays* are also present, being continuous with the rays of the xylem. They increase in width uniformly and gradually as they recede from the cambium.

In practically all cases of growth in thickness the epidermis is destroyed at an early period and is replaced by *cork.* Cork is suberised tissue formed by a special meristem called *cork cambium* or *phellogen,* which originates in the epidermis or in the cells just beneath the epidermis. All parenchymatous cells, however, wherever located, appear to possess the ability to form cork. Wound surfaces are closed and healed by it, and diseased and dead parts are isolated from those in living condition.

The formation of cork cambium in the bark usually occurs during the first year's growth of the stem. As a result of its activity a layer of cork cells is generated on the outside, and frequently a layer of thin-walled parenchyma cells—the *phelloderm*—on the inside. Collectively these new tissues, including the cork cambium, are called the *periderm.* The effect of the development of cork is to cut off from the interior mass of tissue portions of the cortex, which dry up and are eventually thrown off as outer bark. This action may occur only once, as in *Fagus* and *Carpinus,* but usually is repeated, and successively deeper layers of the cortex and eventually of the pericycle and phloem are cut off.

In some species the successive formations of cork extend more or less uniformly around the stem, cutting off in each case an annular layer of cortex—sometimes called *ring bark.* In other species the successive internal layers are very irregular, and cut

off scale-like portions of the cortex—*scale-bark*. The results are subject to very wide variation.

In *Platanus* and *Taxus* the outer bark is shed annually in the form of comparatively large, irregular, thin flakes which, falling away, leave the surface smooth. In species of *Betula* thin, exfoliating layers are produced, marked with horizontal lines of *lenticels*. In many species of *Pinus*, the outer bark of mature trees is made up of small, irregular scales in very intricate pattern. In *Hicoria ovata* and *H. laciniosa* the outer bark peels off in long, flat, reddish-brown strips, while several other species of the same genus have bark that is not flaky. In a great many woody plants the layers of bark persist for many years, and, as the stem increases in size, become more and more cracked and furrowed. Such is the case in *Quercus*, *Robinia*, *Liriodendron*, etc. In *Sequoia*, *Juniperus*, *Taxodium*, and others of the Cedar group, the bark is characteristically fibrous. These examples are sufficient to indicate the wide variation in the bark and its importance as an aid to the identification of a specimen upon which any portion of bark remains.

The bark of many trees is of high technical value. A very great number are used for medicinal purposes. *Tsuga* and species of *Quercus* possess barks which furnish a large proportion of our tannin supply, upon which the leather industry is dependent. Some barks contain coloring principles; others (*e.g.*, *Hicoria ovata*) are highly valuable for fuel. Birch bark was formerly used for canoes. The inner barks of some woods (*e.g.*, *Tilia*) are sometimes used in manufacturing fibre cloth. The highly-developed corky layers of *Quercus suber* furnish the cork of commerce.

### *References*

STEVENS, W. C.: Plant Anatomy, Philadelphia, 1907, pp. 37–39; 56–58; 72–82.

DEBARY, A.: Comparative Anatomy, pp. 108–114; 519–566.

SACHS, JULIUS: Text-Book of Botany, Oxford, 1875, pp. 90–92.

GREGORY, E. L.: Elements of Plant Anatomy, Boston, 1895, pp. 133–142.

HENKEL, ALICE: American Medicinal Barks, Bul. 139, U. S. Bu. Plant Industry, 1909, p. 59.

HILL, ARTHUR W.: Sieve-Tubes of Gymnosperms, Annals of Botany, Vol. XV, Dec. 1901.

————: Notes on the Histology of the Sieve-tubes of Certain Angiosperms, Annals of Botany, Vol. XVII, Jan. 1903, pp. 265–267.

MOELLER, JOSEPH: Anatomie der Baumrinden; Vergleichende Studien, Berlin, 1882, p. 447.

## PRIMARY WOOD

At the growing apex of a stem is an undifferentiated tissue composed of very thin-walled cells essentially all alike. This tissue is known as the *primordial meristem.*

Below the apex the primordial meristem becomes differentiated into three distinct parts, viz., (1) the *protoderm* at the outside, (2) the *procambium strands*, and (3) the *fundamental* or *ground meristem.* These three regions or tissues are themselves subject to further differentiation and are called *primary meristems.* The protoderm changes into the epidermis; the ground meristem into pith, primary rays, pericycle, and primary cortex; the procambium strands into vascular bundles, which are disposed in a circle around the pith and separated from each other by the primary rays. The *vascular bundles* are composed of three parts, an inner called the *xylem*, an outer called the *phloem*, and, separating the two, a thin layer of generative tissue, the *cambium.* These tissues, being the direct development of the cells of the procambium, are termed *primary* (*primary wood* or *proto-xylem*, and *primary phloem* or *proto-phloem*), in contradistinction to the tissues generated by the cambium, which are termed *secondary.*

Primary wood is relatively unimportant, though of scientific interest because of its peculiar structure, which in many ways differs from the other wood of the stem. Thus in Angiosperms, wood fibres are usually wanting and tracheids are not common in the primary wood, while in the secondary wood fibres are always present and tracheids commonly so. In Gymnosperms the vascular elements of the primary wood are indeterminate in length, marked with spirals and for the most part devoid of pits in their walls, while the corresponding elements in the secondary wood are of determinate length, rarely marked with spirals and always pitted.

### *References*

STEVENS, WILLIAM C.: Plant Anatomy, pp. 25–45.

PENHALLOW, D. P.: North American Gymnosperms, pp. 38, 40.

DEBARY, A.: Comparative Anatomy, p. 321.

SACHS, J.: Text-Book of Botany, p. 574.

### CAMBIUM

As previously stated, that portion of a pro-cambium strand which remains capable of division and generation is known as *fascicular* (*i.e.*, bundle) cambium, since it produces on the inner side wood or xylem, and on the outer phloem—collectively a fibro-vascular bundle. The cambia of the several bundles are later united into a continuous sheath, and the portion between the original bundles is termed the *inter-fascicular* cambium. The cambial layer sheathes the entire woody cylinder from root to branch and separates it from the cortex or bark. It is composed of a thin layer of delicate, thin-walled, vertically elongated cells filled with protoplasm and plant food. It is this layer that is torn when bark is stripped from a living tree. During vigorous growth, "when the sap is up," the cells of the cambium are particularly delicate, a fact taken advantage of in peeling poles, logs, and basket-willow rods.

The division and development of the cambial cells give rise to (*a*) a layer of new wood on the outside of that last produced; (*b*) a layer of new phloem on the inside of that last produced; (*c*) continuation of the medullary rays of both xylem and phloem; and (*d*) new cambium.

#### *References*

DEBARY, A.: Comparative Anatomy, pp. 454–475.

BAILEY, I. W.: Relation of Leaf-Trace to Compound Rays in Lower Dicotyledons, Annals of Botany, Vol. XXV, No. 97, June 1911.

RUBNER, KONRAD: Das Hungern des Cambiums und das Aussetzen der Jahrringe, Naturw. Zeitschrift für Forst- und Landwirtschaft, 8. Jahrgang, 1910, pp. 212–262.

VON MOHL, HUGO: Ueber die Cambiumschicht des Stammes der Phanerogamen und ihr Verhältniss zum Dickenwachsthum desselben, Bot. Zeitung, Vol. XVI, 1858, pp. 183–198.

### SECONDARY WOOD

Tissues formed from cambium are termed *secondary*. Almost all of the wood of a stem is secondary wood, the small amount of primary wood being wholly negligible from a technological point of view.

The principal functions of secondary wood are (*a*) to provide

mechanical support for the tree; (*b*) to afford means for the ascent of sap from the roots to the foliage; (*c*) alternately to store up and to give back products of assimilation, particularly starch.

While the elements of secondary wood are subject to wide variation, they may for convenience be referred to three principal types, viz., (1) *vascular*, (2) *fibrous*, (3) *parenchymatous*. Between these groups are transitional and specialized forms whose reference to one or the other of these groups is often purely arbitrary. The classification may be extended as follows:

| | |
|---|---|
| *Vascular elements* | *Fibrous elements* |
| True vessels | Wood fibres |
| Tracheids | Septate wood fibres |
| (wood) tracheids | *Parenchymatous elements* |
| ray tracheids | Wood parenchyma |
| | Ray parenchyma |

In the following table are shown side by side the important differences in the distribution of the elements in typical secondary wood of Gymnosperms and Dicotyledons.

| *Gymnosperms* | *Dicotyledons* |
|---|---|
| True vessels absent. | True vessels present. |
| Wood tracheids present and forming bulk of wood. | Tracheids present or absent; always subordinate. |
| Ray tracheids present or absent. | Ray tracheids absent. |
| Wood fibres absent. | Wood fibres present. |
| Wood parenchyma present (except in *Taxaceæ*), but usually subordinate. | Wood parenchyma present, and very often conspicuous. |
| Ray parenchyma present. | Ray parenchyma present. |

From the above it is apparent that the wood of Dicotyledons is more heterogeneous in its nature than that of Gymnosperms, which is composed almost wholly of tracheids and ray parenchyma.

*References*

SOLEREDER, H.: Anatomy of the Dicotyledons, Vol. II, pp. 1133–1168.

DEBARY, A.: Comparative Anatomy, pp. 458–500.

BOULGER, G. S.: Wood, London, 1908, pp. 1–54.

STEVENS, W. C.: Plant Anatomy, pp. 48–56; 72–112.

SACHS, J.: Text-Book of Botany, pp. 92–102.

MELL, C. D.: A Confusion of Technical Terms in the Study of Wood Structure, For. Quarterly, Vol. IX, No. 4, 1911, pp. 574–576.

———: Classification of Woods by Structural Characters, Am. Forestry, Vol. XIV, April 1910, pp. 241–243.

STONE, H.: The Use of Anatomical Characters in the Identification of Wood, Nature, Vol. LXV, No. 1686, 1902, pp. 379–380.

GAYER, K.: Schlich's Manual of Forestry, Vol. V, 1908, pp. 7–19.

METZGER, K.: Ueber der Konstructionsprinzip des secundären Holzkörpers, Naturw. Zeitschrift für Forst- und Landwirtschaft, 6. Jahrgang, 1908, pp. 249–273.

WIELER, A.: Ueber die Beziehung zwischen Wurzel- und Staumholz, Forstw. Jahrbuch, Tharand, Vol. XLI, 1891, pp. 143–171.

HARTIG, ROBERT: Untersuchungen über die Entstehung und die Eigenschaften des Eichenholzes, Forstlich-naturw. Zeitschrift, Vol. III, 1894, pp. 1–13; 49–68; 172–191; 193–203.

HARTIG, ROBERT, AND WEBER, RUDOLPH: Das Holz der Rothbuche in Anatomisch-physiologischer, Chemischer und Forstlicher Richtung, Berlin, 1888, pp. 20–28.

SANIO, CARL: Vergleichende Untersuchungen über die Elementarorgane des Holzkörpers, Botanische Zeitung, Vol. XXI, 1863, pp. 85–128.

————: Verg. Unt. ü. d. Zusammensetzung des Holzkörpers, *Ibid.*, Vol. XXI, 1863, pp. 358–412.

WIESNER, JULIUS: Die Rohstoffe des Pflanzen Reiches, Vol. II, Leipzig, 1903, pp. 1–35.

## VESSELS

*Vessels* are indeterminate, tube-like elements present in the wood of all indigenous dicotyledonous plants. In fact the absence of xylem vessels in woody Dicotyledons is a very rare phenomenon which, according to Solereder (*loc. cit.*, p. 1136), has been recorded only in the exotic genera *Drimys* and *Zygogynum* of the *Magnoliaceæ*, and *Tetracentron* and *Trochodendron* of the *Trochodendraceæ*.

Vessels arise from cambial cells which increase in size and, through the partial or complete absorption of their end-walls at the close of the process of thickening, become continuous in a longitudinal row. There is always a constriction at the place of fusion of the cells, thus plainly demarking the *vessel segments* (Plate VI, Nos. 3, 4, 6). The walls of contact of the segments of a vessel are sometimes (*a*) horizontal, but more often (*b*) oblique, and fit together exactly; or, again, they may be (*c*) oblique with a portion of the opposed faces united, the pointed and blind ends extending beyond the division wall, as in *Liquidambar* and *Quercus*. In (*a*) the perforation from one segment to another is *simple, i.e.*, with one round opening. In (*b*) and (*c*) the perforations are sometimes

simple and sometimes, especially in strongly inclined division walls, *scalariform*, that is, the opening is crossed with few to many bars in ladder-like arrangement. The bars are usually transverse to the longitudinal axis of the vessel. Both simple and scalariform perforations may occur side by side in the same wood, but usually one form prevails. These features have considerable diagnostic value. For example, the perforations are simple in *Acer*, but scalariform in *Betula* and *Cornus;* in *Æsculus* and *Tilia* they are mostly simple, but in *Liriodendron* and *Magnolia* scalariform.

Other characteristics of the vessels are the markings on their walls. In most cases they are abundantly pitted with bordered pits, except in contact with parenchymatous cells where the pitting may be either simple or bordered. (See PITS.) It is very common for vessels, particularly the small ones, to be marked with spirals on their interior walls (*e.g., Acer, Ilex, Tilia, Ostrya, Æsculus*). In *Liquidambar* only the pointed ends of the vessel segments are marked with spirals.

The function of vessels is to facilitate the ascent of water in the stem. Vessels lose their protoplasmic contents by the time their perforations are complete and become filled with air and water, or air alone. When their activity as water-carriers lessens they frequently become plugged with outgrowths from adjoining parenchymatous cells. (See TYLOSES.) In the heartwood of certain species (*e.g., Gymnocladus, Gleditsia, Guaiacum, Prosopis*) they become wholly or partly filled with gums or resins; in others, with carbonate of lime.

The length of vessels is usually very great, and doubtless often equals that of the whole plant. In width vessels exhibit great variation not only in different species, but also in different portions of the same growth ring. In some woods all of the vessels are small (*e.g., Tilia, Æsculus* [Plate VI, Fig. 5], *Populus, Salix*); in others they are mostly large (*e.g., Juglans*); very often, as in *Quercus* (Plate II, Figs. 5, 6), they vary from large (0.6 mm.*) and conspicuous to very small (0.1 mm.).

Vessels in cross section are called *pores*, and when this term is employed it will be understood to apply to cross sections exclusively. Pores are usually readily distinguishable from the adjoining elements by their larger size, though it is not always

* One millimetre is equal to about one twenty-fifth of an inch.

possible to tell small pores from cross sections of tracheids. In outline pores may be round, elliptical, or angular. The first two cases are the rule where the vessel walls are thick enough to resist the pressure of the surrounding elements. This is the case, for example, in the small pores of the red and live oaks (Plate II, Fig. 6), while in the white oaks (Frontispiece; Plate II, Fig. 5) the walls are thin and the pores angular in outline. Sometimes pores are disposed in rings or zones in the early wood of the growth ring, producing ring-porous woods (Plate III); in other cases they are scattered singly or in groups throughout the ring or arranged in radial or tangential rows, producing diffuse-porous woods (Plate VI). (See GROWTH RINGS.) In any case the largest pores are almost invariably in the first formed wood of the season. The distribution, size, form, and arrangement of the pores are characters of great importance in classifying woods.

*References*

SOLEREDER, H.: Anatomy of the Dicotyledons, Vol. II, p. 1136.

MELL, C. D.: History of the Investigations of Vessels in Wood, Proc. Soc. Am. Foresters, Vol. VI, No. 1, 1911, pp. 78–91.

DEBARY, A.: Comparative Anatomy, pp. 155–171; 503.

MAYR, H.: Schlich's Manual of Forestry, Vol. V, 1908, pp. 9–10.

SANIO, CARL: Bot. Zeitung, Vol. XXI, No. 15, 1863, pp. 121–128.

HARTIG, R.: Lehrbuch der Anatomie und Physiologie der Pflanzen, Berlin, 1891, pp. 79–93.

## TRACHEIDS

*Tracheids* are elongated, spindle-shaped, fibre-like elements, determinate in length and characterized by bordered pits in their side-walls.

In the wood of Gymnosperms the tracheid is the dominant element, performing the dual function of conducting water and providing mechanical support for the tree. Bordered pits are mostly confined to the radial walls, except in late wood, and are most abundant near the ends of the tracheids and in one or two rows (Fig. 2, *D*). Seen in cross section, the tracheids are polygonal in outline, arranged in radial rows, and, near the periphery of growth ring, with very appreciable increase in thickness of the wall, reduction of the lumen, and tangential flattening (Fig. 8; Plate II, Figs. 1, 2, 4). In a few species, particularly *Pseudotsuga*,

*Taxus,* and *Tumion,* the tracheids are characterized by spiral thickenings on the inner wall.

TABLE I

LENGTH OF TRACHEIDS IN CONIFEROUS WOODS

| BOTANICAL NAME | Average mm. | Maximum mm. | Minimum mm. |
|---|---|---|---|
| Abies balsamea | 3.10 | 4.20 | 2.00 |
| " concolor | 4.65 | 6.00 | 2.75 |
| " grandis | 4.15 | 5.70 | 2.90 |
| Chamæcyparis lawsoniana | 3.60 | 4.35 | 2.55 |
| " thyoides | 2.10 | 2.80 | 1.45 |
| Larix occidentalis | 2.60 | 3.80 | 1.75 |
| Libocedrus decurrens | 4.00 | 4.70 | 3.00 |
| Picea engelmanni | 5.70 | 6.95 | 3.05 |
| " rubens | 2.95 | 3.65 | 2.50 |
| " sitchensis | 2.85 | 3.70 | 2.30 |
| Pinus echinata | 5.90 | 7.20 | 4.40 |
| " edulis | 1.95 | 2.55 | 1.50 |
| " lambertiana | 4.45 | 5.85 | 2.75 |
| " monticola | 4.40 | 5.45 | 2.75 |
| " murrayana | 2.65 | 3.70 | 1.80 |
| " palustris | 5.55 | 6.70 | 3.00 |
| " ponderosa | 3.30 | 4.00 | 2.50 |
| " resinosa | 4.05 | 4.80 | 3.20 |
| " strobus | 3.55 | 4.55 | 3.20 |
| " tæda | 3.10 | 3.90 | 2.55 |
| " virginiana | 2.75 | 3.95 | 1.75 |
| Pseudotsuga taxifolia | 2.70 | 3.30 | 1.80 |
| Sequoia sempervirens | 7.00 | 9.25 | 4.05 |
| " washingtoniana | 4.80 | 5.95 | 3.45 |
| Taxodium distichum | 4.70 | 5.80 | 3.65 |
| Thuya occidentalis | 2.00 | 2.40 | 1.40 |
| " plicata | 3.85 | 4.55 | 3.15 |
| Tsuga canadensis | 4.00 | 5.05 | 2.80 |
| " heterophylla | 3.05 | 3.65 | 1.75 |

In certain conifers, particularly *Pinus,* specialized forms of tracheids of a parenchymatous type are found associated with resin ducts and cysts. They resemble wood-parenchyma cells in form and function, but have bordered pits in their side and end walls. Analogous to them are the ray tracheids found in several genera of conifers. (See RAYS.)

The tracheids of broadleaf woods (Fig. 2, *E*) are subordinate

elements often entirely wanting. They are much smaller and less uniform in size and shape than in conifers, and are of most common occurrence in the immediate vicinity of vessels. Their ends are often curved, especially when they terminate just above or below a ray. The walls are usually comparatively thin and bear numerous bordered pits very irregularly distributed. Intermediate forms of tracheids are sometimes found which show distinct transition to the vessels in the detailed structure of their walls and in the occasional presence of perforations at the ends of the cells.

*References*

Penhallow, D. P.: North American Gymnosperms, pp. 33–58.

DeBary, A.: Comparative Anatomy, pp. 164–165.

Thompson, W. P.: On the Origin of Ray Tracheids in the Coniferæ, Bot. Gazette, Vol. L, 1910, pp. 101–116.

Kny, L.: Ein Beitrag zur Entwickelungsgeschichte der "Tracheiden," Ber. d. deutschen Bot. Gesellschaft, Vol. IV, 1886, pp. 267–276.

Sanio, Carl: Botanische Zeitung, Vol. XXI, No. 14, 1863, pp. 113–118.

## WOOD FIBRES

Typical *wood fibres* (Fig. 2, *A*, *B*) are slender, spindle-shaped, sharp-pointed cells with thick walls and narrow cavities. They are further characterized by usually oblique and slit-like simple pits, or less frequently by small, indistinctly bordered pits. Wood fibres are not found in Gymnosperms, but are nearly always present in the wood of Dicotyledons.

Wood fibres are of two types, *septate* and ordinary (*non-septate*). The septate forms are divided by cross-partitions formed after thickening of the walls has begun. They are of limited occurrence and of relatively small importance. They are characteristic of *Swietenia mahagoni* and serve as one means of distinguishing the wood from that of certain others closely resembling it.

The ordinary forms are very common and are the principal source of strength, hardness, and toughness of broadleaf woods. While their function is largely mechanical, it is probable that they, especially those with bordered pits, play some part, as yet undetermined, in water transportation.

Wood fibres exhibit transitional forms from the typical to tracheids on one hand, and to wood-parenchyma fibres on the

other. In structure and arrangement they exhibit variations of considerable taxonomic value. For example, in *Ilex* the fibres are rather thin-walled and marked with spirals and bordered pits, and closely resembling tracheids except for their greater size. In *Liquidambar* (Plate VI, Fig. 1) the fibres are mostly square in cross section and in rather definite radial arrangement. In

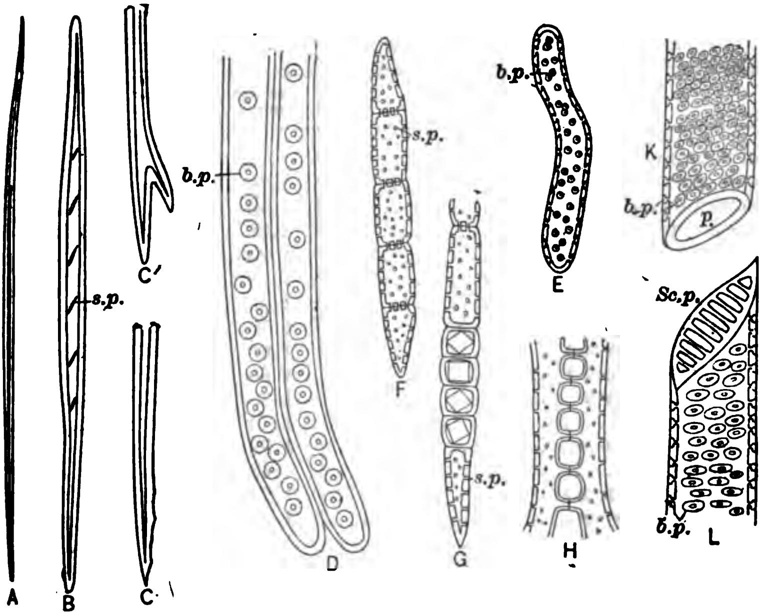


FIG. 2.—Typical Wood Cells. *A*, Wood fibre with very narrow lumen; *B*, wood fibre with larger lumen and showing oblique, slit-like simple pits (*s. p.*); *C*, end of wood fibre showing saw edge; *C′*, end of wood fibre showing forked structure; *D*, ends of two tracheids from *Pinus* showing numerous bordered pits (*b. p.*); *E*, Tracheid from *Quercus*; *F*, wood-parenchyma fibre, showing individual cells and simple pits (*s. p.*); *G*, chambered wood-parenchyma fibres from *Juglans*, showing crystals of calcium oxalate; *H*, conjugate parenchyma cells; *K*, portion of a vessel segment showing simple perforation (*p*); *L*, portion of a vessel segment showing scalariform perforation (*Sc. p.*). Greatly enlarged.

*Robinia* (Plate III, Fig. 3) and *Toxylon* they are in rather large, compact masses in the late wood, separated by groups or bands of pores and parenchyma. In any wood in which they occur they are most abundant in the median portion of the growth ring, and material decrease in the width of a ring is usually at their expense.

The ends of most wood fibres are smooth and uniformly

tapering, but sometimes they are flattened, or forked, or with a saw edge (Fig. 2, *C*, *C'*), adding to the toughness of the wood. Fibres usually run parallel to one another, but in some woods they exhibit a decided interweaving which produces an irregularly grained wood very difficult to split.

TABLE II

LENGTH OF WOOD FIBRES IN DICOTYLEDONOUS WOODS

| BOTANICAL NAME | Average mm. | Maximum mm. | Minimum mm. |
|---|---|---|---|
| Acer rubrum | .75 | 1.00 | .50 |
| Betula nigra | 1.80 | 2.20 | 1.50 |
| Castanea dentata | 1.15 | 1.45 | .80 |
| Celtis occidentalis | 1.25 | 1.70 | 1.05 |
| Fagus americana | 1.20 | 1.70 | .75 |
| Hicoria alba | 1.35 | 1.70 | .90 |
| Ilex opaca | 1.45 | 2.00 | 1.15 |
| Juglans nigra | 1.10 | 1.65 | .65 |
| Liquidambar styraciflua | 1.60 | 2.00 | 1.25 |
| Liriodendron tulipifera | 1.90 | 2.50 | 1.40 |
| Magnolia acuminata | 1.75 | 2.30 | 1.00 |
| Nyssa sylvatica | 1.70 | 2.35 | 1.05 |
| Platanus occidentalis | 1.90 | 2.30 | 1.30 |
| Populus deltoides | 1.40 | 2.20 | .50 |
| " grandidentata | 1.00 | 1.35 | .65 |
| " heterophylla | 1.35 | 1.80 | 1.00 |
| " trichocarpa | 1.15 | 1.90 | .50 |
| Quercus alba | 1.25 | 1.50 | 1.00 |
| " coccinea | 1.50 | 2.10 | 1.00 |
| " michauxii | 1.55 | 1.80 | 1.10 |
| " rubra | 1.20 | 1.45 | .70 |
| " virginiana | 1.40 | 1.80 | .85 |
| Salix nigra | .85 | .95 | .45 |
| Tilia americana | 1.15 | 1.45 | .85 |
| Ulmus americana | 1.50 | 1.90 | 1.15 |

*References*

DEBARY, A.: Comparative Anatomy, pp. 481–483.

SOLEREDER, H.: Anatomy of the Dicotyledons, Vol. II, pp. 1141–1143.

GREGORY, E. L.: Pores of the Libriform Tissue, Bull Torrey Bot. Club, Vol. XIII, 1886, pp. 197–204; 233–244.

ANONYMOUS: Length of Wood Fibers in Broadleaf Woods, Sc. American Sup., Sept. 30, 1911, p. 211.

SANIO, CARL: Bot. Zeitung, Vol. XXI, No. 13, 1863, pp. 89–111.

### WOOD PARENCHYMA

Parenchyma occurs in the secondary xylem of all woody plants, and, with few exceptions, is disposed in two systems: (1) the vertical, composed of more or less scattered rows of cells forming the *wood parenchyma;* and (2) the horizontal, made up of plates of cells extending radially and at right angles to the axis—the *medullary rays* or *pith rays.* Its chief function is the distribution and storage of elaborated food materials.

Typical wood-parenchyma fibres (Fig. 2, *F;* Plate IV, Figs. 5, 6) of Dicotyledons resemble septate wood fibres, but have (1) thinner walls, (2) invariably simple, rounded pits instead of oblique, slit-like simple or bordered pits, and (3) cross walls equal in thickness to the lateral walls. The individual cells of a wood-parenchyma fibre are mostly short and prismatic, pitted with simple pits and (with the exception of the terminal ones, which are pointed) with transverse or oblique end walls. Between wood fibres and wood-parenchyma fibres are intermediate forms without septa—*substitute fibres* or *intermediate wood fibres.*

Where wood parenchyma borders on large vessels it is usually much flattened as a result of the pressure of the expanding vessel segments. In such locations also are sometimes special forms termed *conjugate cells* because of flatly tubular processes extending from one to another slightly distant, thus uniting them (Fig. 2, *H*).

There are special forms of wood parenchyma in which the individual cells are divided by cross walls into small chambers of approximately even size which contain solitary crystals, usually of calcium oxalate (Fig. 2, *G;* Plate IV, Fig. 6). Such crystals are only slightly soluble even in the strongest acids, and are very plainly visible under high magnification in both cross and longitudinal sections. Crystals occur in all species of *Quercus,* though they are commonly more abundant in the live oaks than in deciduous species. In *Juglans* (Plate IV, Fig. 6), *Hicoria* (Plate IV, Fig. 3), and *Diospyros,* crystals are often quite conspicuous. Calcium-oxalate crystals are also common in ray-parenchyma cells.

The distribution and arrangement of wood-parenchyma fibres in different species are subject to considerable variation. As seen on cross sections of woody Dicotyledons the fibres may be (*a*) scattered irregularly throughout the growth ring (Plate V, Figs. 3, 5), (*b*) arranged in tangential lines or bands (Frontispiece,

Plate IV, Figs. 1, 2), (*c*) terminal, *i.e.*, comprising the outer limit of the growth ring (Plate III, Fig. 6; Plate V, Fig. 2; Plate VI, Fig. 2), (*d*) surrounding pores (Plate III, Figs. 3, 5), (*e*) arranged in radial rows. These features are quite important in classifying woods. For example, in *Fraxinus americana* the pores in the late wood are usually joined tangentially by narrow bands of wood parenchyma, while in *F. nigra* (Plate V, Fig. 2) the pores are rarely so united. In *Hicoria* (Plate IV, Fig. 1) wood parenchyma is in numerous, fine, concentric lines as distinct as the rays, while in *Diospyros* (Plate IV, Fig. 2) the lines are finer than the rays and very indistinct. In *Tilia* wood parenchyma is in tangential lines, but is not so disposed in *Liriodendron*, *Magnolia*, and *Æsculus*. In *Liriodendron* (Plate VI, Fig. 2) and *Magnolia* the outer limit of the growth ring consists of 2–4 rows of tangentially flattened wood-parenchyma fibres with very thick, copiously pitted radial walls.

Wood parenchyma is present in the wood of all Gymnosperms except the *Taxaceæ*. The cells are invariably associated with resin formation and are usually referred to as *resin cells* or *epithelial cells*, according as they are more or less scattered or surrounding resin ducts.

Resin cells are usually cylindrical or prismatic, thin-walled, with transverse terminations more or less strongly marked with simple pits. The pits in the side walls are often few and invariably simple. Resin cells can usually be distinguished on cross sections under the microscope by their thin walls, simple pits, or better by the deep color of their contents. If the section passes near enough to an end wall the simple pits therein give the appearance of a sieve plate (Fig. 10). While in most cases resin cells are invisible without the microscope, and often not readily found with it, yet in *Juniperus*, *Taxodium*, and *Sequoia* they are usually conspicuous, not infrequently giving rise in the first two species to wavy tangential lines in the growth ring, visible to the unaided eye.

The distribution of the resin cells is variable. In some cases (*e.g.*, *Thuya*) they are scattering; in others (*e.g.*, *Taxodium* [Plate II, Fig. 1], *Juniperus* [Plate II, Figs. 3, 4], *Libocedrus*) they are disposed in well-defined zones concentric with the growth ring, being most abundant as a rule in the transition zone between early and late wood. In still other cases (*e.g.*, *Tsuga*) there is often a tendency of some of the resin cells to aggregation, and in

some cases the formation of imperfect resin ducts or resin cysts (Fig. 10). (See RESIN DUCTS.)

In *Pinus* (Fig. 8) wood parenchyma is found only in association with resin ducts, isolated resin cells being absent; while in *Larix* and *Pseudotsuga* resin cells are occasionally found on the extreme outer face of the late wood. In *Abies* resin cells are remote and inconspicuous; in *Thuya plicata* they are present, though often zonate in widely separated growth rings, thus often apparently absent. In *Sequoia* (particularly *S. sempervirens*) the resin cells are partially filled with dark resin masses which appear on longitudinal surface as fine dotted lines, or under lens as rows of black or amber beads.

*References*

DEBARY, A.: Comparative Anatomy, pp. 485–486.

PENHALLOW, D. P.: North American Gymnosperms, pp. 109–122.

BOULGER, G. S.: Wood, pp. 28–29.

SANIO, CARL: Bot. Zeitung, Vol. XXI, No. 12, pp. 93–98.

KNY, L.: Ueber Krystallbildung beim Kalkoxolat, Berichte der deutschen Bot. Gesellschaft, Vol. V, 1887, pp. 387–395.

## RAYS

Medullary or pith rays, for brevity termed simply *rays*, appear on the cross section of a stem as radial lines crossing the growth rings at right angles and extending into the bark (Fig. 1). A few of them originate at the pith and are commonly known as *primary rays*. Successively, as the stem increases in size, additional or *secondary rays* arise between those already formed. A ray may arise in the cambium layer at any point, and once formed its growth is continuous.*

Under the microscope the line formed by the ray becomes a radial series of mostly elongated cells usually with transverse end walls (Plates II–IV). Viewed radially a ray appears as a muriform structure composed of from one to many tiers of brick-shaped cells (Plate IV, Figs. 5, 6). In tangential section the ends of the rays are visible, showing to advantage their height, shape,

* When on cross or radial sections a ray appears to be discontinuous, it is probable that it has merely been missed by the plane of section. This emphasizes the importance of making cross sections exactly at right angles to the axis of growth, and radial sections as nearly as possible parallel with the rays.

width, and distribution, and also the outline in cross section of the component cells (Plate III, Fig. 1; Plate IV, Figs, 3, 4; Plate VI, Figs. 3, 4, 6).

Ray cells are usually elongated in the radial direction. This is normally the case in Gymnosperms and usually so in the woody Dicotyledons. Not infrequently in the latter, however, part or all of the cells are *upright*, *i.e.*, with their greatest diameter vertical, or are square. The marginal cells are sometimes upright and the interior cells radially elongated or *procumbent* (Fig. 3). The upright cells are often very irregular, especially the outermost marginal rows; sometimes they are nearly square; again they are in palisade arrangement. When these upright or square cells are in

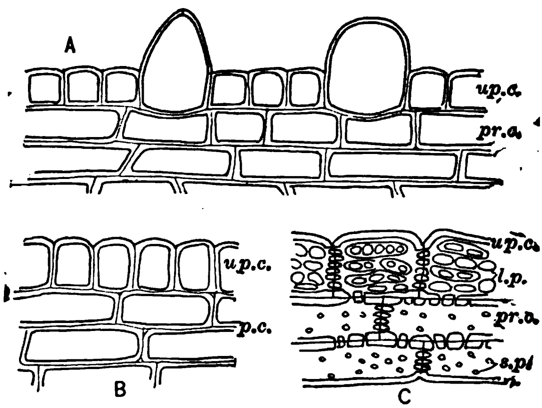


FIG. 3.—Radial sections of heterogeneous rays. *A*, *Sassafras sassafras* (sassafras); *B*, *Nyssa sylvatica* (black gum); *C*, *Æsculus octandra* (buckeye), showing large pits (*l. p.*) in upright cells (*up. c.*), where they adjoin vessels; and small pits (*s. p.*), in procumbent cells (*pr. c.*). No pits are shown in *A* and *B*. Magnified about 150 diameters.

contact with large vessels the separating walls are characteristically marked with very large pits whose polygonal or oval outlines present the appearance of lattice work (Fig. 3, *C*). The lateral walls of similarly located procumbent cells usually contain few small pits. Moreover, in proximity to large vessels the walls between all ray cells are usually thicker and much more abundantly pitted than elsewhere. Upright cells are not always easy to distinguish from the cells of wood-parenchyma fibres, especially where they cross the latter, on account of the similar direction of their longitudinal diameters.

Rays consisting wholly of procumbent cells may be said to be *homogeneous;* those which contain both upright and procumbent cells, *heterogeneous* (Fig. 3). Heterogeneous rays are characteristic of many dicotyledonous woods, and are features of importance in classification. For example, *Celtis* has heterogeneous rays, while those of *Ulmus* are homogeneous. The same distinction obtains between *Salix* and *Populus*, *Sassafras* and *Fraxinus*. The rays of *Sassafras* are peculiar in having a few of the marginal cells abnormally large and rounded or ovate (Fig. 3, *A*).

The rays in the wood of Gymnosperms are for the most part one cell wide, *i.e.*, uniseriate, and from 1 to 20 cells high. It is not

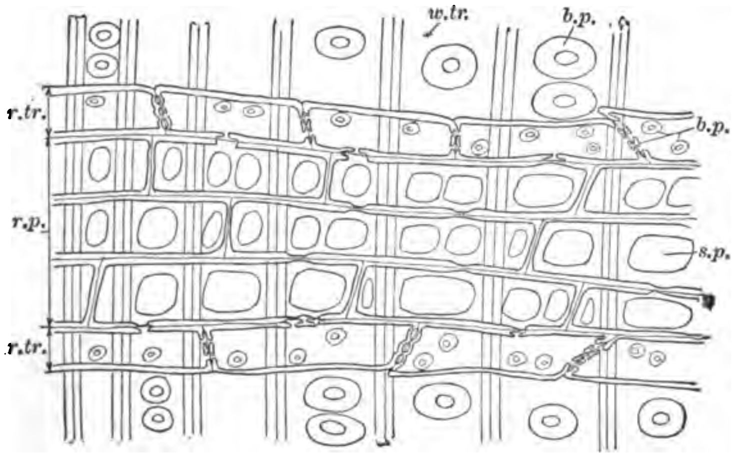


FIG. 4.—Radial section of ray of *Pinus strobus* (white pine); showing the smooth upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of large simple pits (*s. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pits. Magnified about 250 diameters.

uncommon to find biseriate rays, and those which contain resin ducts (*Pinus, Picea, Larix, Pseudotsuga*) are multiseriate. The latter, because of their shape as seen on tangential section, are called *fusiform rays* (Fig. 9).

In woody Dicotyledons there is more variation in the rays. In some instances (*e.g.*, *Æsculus* [Plate VI, Fig. 6], *Salix, Populus*) low uniseriate rays only are present. At the other extreme is *Quercus* (Plate III, Fig. 1), where the largest rays are from 25 to

75 cells wide and several hundred high. These large rays give rise to the handsome figure of quarter-sawed (*i.e.*, radially cut) oak lumber. Besides the large rays in *Quercus* there are numerous intermediate ones, mostly uniseriate and 1–20 cells high (Plate III, Fig. 1). In *Platanus* the rays are uniformly broad (10–15 cells), while in *Fagus* only a portion of the rays are broad (15–25 cells), the intermediate ones being uniseriate. In some of the evergreen oaks, *Carpinus* and species of *Alnus* (Plate V, Figs. 3, 4), the large rays appear to be composed of numerous small ones

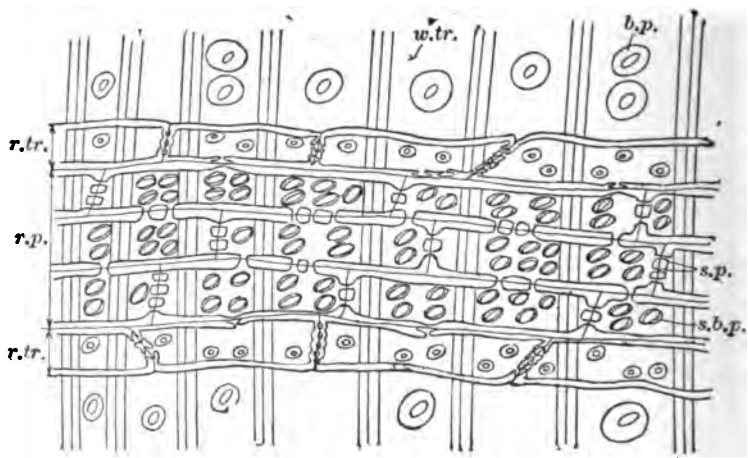


FIG. 5.—Radial section of a ray of *Pinus edulis* (piñon pine), showing the smooth upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of small semi-bordered pits (*s. b. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *s. p.*, simple pit; *b. p.*, bordered pit. Magnified about 250 diameters.

separated by wood fibres. Such rays are termed *aggregate* or *compound* rays; sometimes also *false rays*. Every ray, regardless of its width at the middle, tapers to an edge so that the upper and lower margins are a single cell wide.*

The comparative distinctness which rays on cross section present to the unaided eye is important in separating certain woods which bear superficial resemblance. For instance, the

* For this reason cross sections often do not afford a correct idea of ray width.

rays in *Sassafras* are much more distinct than in *Fraxinus;* likewise in *Celtis* and *Ulmus, Tilia* and *Æsculus, Acer* and *Betula.* In white oaks the height of the large rays averages considerably greater than in the red or live oaks.

In dicotyledonous species the rays are composed wholly of parenchyma. In certain Gymnosperms (*Pinus, Larix, Picea, Pseudotsuga, Tsuga,* and occasionally in others) ray tracheids are present (Figs. 4–7). They are usually marginal, but often interspersed and sometimes they compose entire rays, particularly

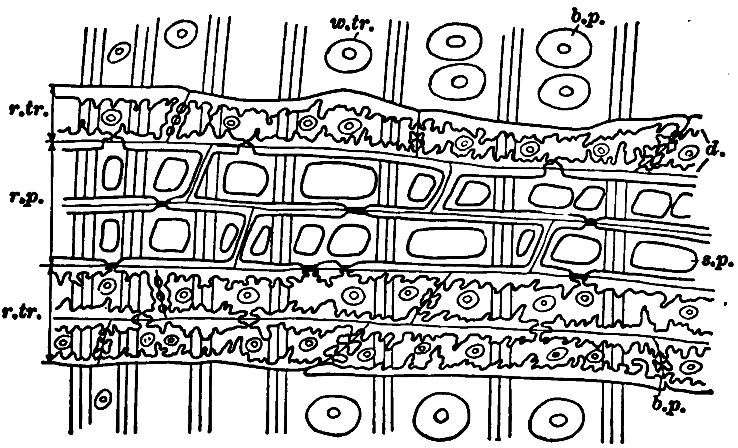


FIG. 6.—Radial section of a ray of *Pinus resinosa* (red or Norway pine), showing the dentations (*d*) or reticulations on the upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*), of large simple pits (*s. p.*) communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pit. Magnified about 250 diameters.

low ones. They can be distinguished from the ray-parenchyma cells by the presence of bordered pits in the lateral and especially the end walls. They are often irregular in outline and are devoid of visible contents. They have their counterparts in the parenchymatous tracheids surrounding the epithelial cells of resin cysts and ducts. In the young root, and sometimes in the young stem as well, special upright or oblique forms occur which may be considered as transitional from wood tracheids to ray tracheids.

The character of the upper and lower walls of the ray tracheids, whether smooth, as in soft pines, or dentate or reticulate, as in

pitch pines, affords a constant diagnostic feature of much importance in separating the two great groups of *Pinus* (Figs. 4–7). Ray-parenchyma cells in general communicate with each other, with the ray tracheids, and with the adjacent wood elements by means of pits always simple in the wall of the parenchyma cell,

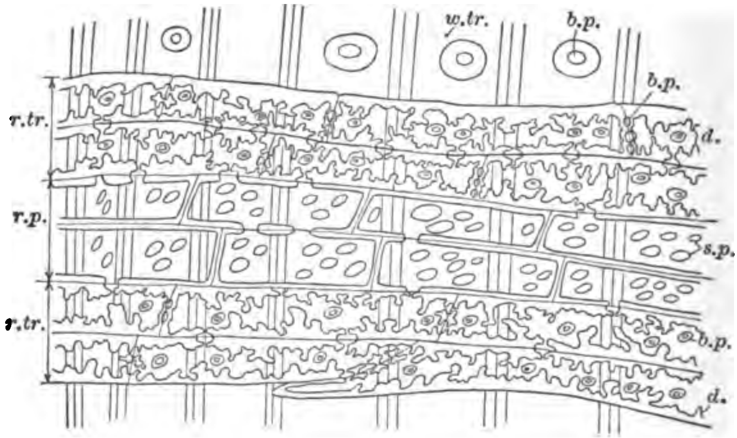


FIG. 7.—Radial section of a ray of *Pinus palustris* (longleaf pine), showing the dentations (*d*) or reticulations on the upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of small simple pits (*s. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pit. Magnified about 250 diameters.

but commonly more or less bordered in the other. Often certain cells of a ray have thicker walls and more numerous pits than the others.

*References*

PENHALLOW, D. P.: North American Gymnosperms, pp. 78–108.

BAILEY, I. W.: On the Origin of the Broad Ray in Quercus, Bot. Gaz., Vol. XLIX, No. 3, March 1910, pp. 161–167.

————: Notes on the Wood Structure of the Betulaceæ and Fagaceæ, Forestry Quarterly, Vol. VIII, No. 2, 1910, pp. 178–185.

————: The Relation of Leaf-Trace to Compound Rays in Lower Dicotyledons, Annals of Botany, Vol. XXV, No. 97, January 1911, pp. 225–241.

GROOM, PERCY: The Evolution of the Annual Ring and Medullary Rays of Quercus, Annals of Botany, Vol. XXV, No. 100, October 1911, pp. 983–1004.

THOMPSON, W. P.: On the Origin of the Multiseriate Ray of the Dicotyledons, Annals of Botany, Vol. XXV, No. 100, October 1911, pp. 1005–1014.

————: The Origin of Ray Tracheids in the Coniferæ, Bot. Gaz., Vol. L, No. 2, 1910, pp. 101–116.

KNY, L.: Beitrag zur Kenntnis der Markstrahlen dicotyler Holzgewächse, Berichte d. deutschen Bot. Gesellschaft, Vol. VIII, Berlin, 1890, pp. 176–188.

ESSNER, BENNO: Ueber den diagnostischen Werth der Anzahl und Höhe der Markstrahlen bei den Coniferen, Halle A. S., 1882. See also Bot. Centralblatt, Vol. XII, No. 12, 1882, pp. 407–408.

ZIJLSTRA, K.: Die Gestalt der Markstrahlen in sekundären Holze, Rec. Trav. bot. néerl., V, 1908, pp. 17–20.

## RESIN DUCTS

*Resin ducts* are long, narrow, intercellular channels surrounded by parenchyma cells and filled with resin (Fig. 8). Unlike vessels, they have no walls of their own, but are limited by a layer of cells called *epithelium*. The epithelial cells are thin-walled in *Pinus* and mostly thick-walled in *Larix*, *Picea*, and *Pseudotsuga*. When thick-walled the cells are rounded and show clearly in cross section, while those with thin walls are compressed and very likely to be torn in sectioning.

*Resin cysts* are very short, duct-like, intercellular spaces very common in *Sequoia*, *Tsuga*, and *Abies*. Not infrequently they are in longitudinal series, but differ from a true duct in having numerous constrictions.

Resin ducts are largest and most abundant in *Pinus*, where they are fairly well distributed throughout the growth ring, though usually more numerous in the transition zone between early and late wood. They are comparatively large in most species, averaging about 0.25 mm., and are readily visible to the unaided eye. On longitudinal surface they appear as long, delicate lines like pin scratches, filled with resin. In *Larix*, *Picea*, and *Pseudotsuga* the ducts are smaller, sometimes invisible without lens, fewer in number, and irregularly distributed, often more or less grouped.

In addition to the ducts extending in a vertical direction, there are horizontal ducts in the *fusiform rays* (Fig. 9). The two series are united at infrequent intervals.

Resin ducts very commonly develop as a result of injury, not only in genera in which they occur normally, but also in others

(*e.g.*, *Tsuga*, *Abies*, *Sequoia*) where normally absent. The formation of these *traumatic resin ducts*, as they are called, following wounding by chipping of the outer layers of the sapwood of *Pinus palustris*, is the source of most of our turpentine and other naval stores. Traumatic ducts can be distinguished from normal ones

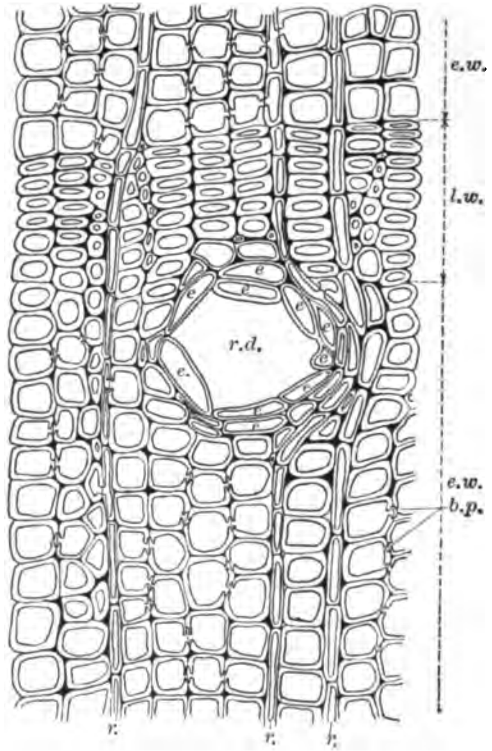


FIG. 8.—Cross section through a portion of two growth rings of *Pinus ponderosa* (western yellow pine); *r. d.*, resin duct; *e.*, epithelial cells; *r.*, ray; *e. w.*, early wood; *l. w.*, late wood; *b. p.*, bordered pit. Magnified about 200 diameters.

by their peculiar localization, usually, as seen on cross section, forming one or more compact rows concentric with the growth ring (Fig. 10). Transverse ducts may also arise traumatically.

Resin ducts do not occur in the wood of indigenous Dicotyledons, but are characteristic of the *Dipterocarpeæ* and certain *Cæsalpineæ*.

In *Leitneria floridana* numerous resin ducts are found at the margin of the pith, but are not in the wood. The epithelial cells are thick-walled and in a single layer.

Resin ducts are features of great systematic importance. Their presence in *Pinus*, *Picea*, *Larix*, and *Pseudotsuga* serves as an adequate basis for separating the woods of these four genera from other Gymnosperms. Their relative size, distribution, and occurrence, and the character of the epithelium, whether thick or thin-walled, are features made use of in specific diagnoses.

*References*

PENHALLOW, D. P.: North American Gymnosperms, pp. 109–153.

KIRSCH, SIMON: The Origin and Development of Resin Canals in the Coniferæ with Special Reference to the Development of Tyloses and their Correlation with the Thylosal Strands of the Pteridophytes, Proc. Royal Soc. of Canada, 1911.

FOXWORTHY, FRED W.: Philippine Dipterocarpaceæ. Phil. Journal of Science, C. Botany, Vol. VI, No. 4, Sept. 1911, pp. 231–287.

SOLEREDER, H.: Anatomy of the Dicotyledons, Vol. II, pp. 1101–1102.

TSCHIRCH, A.: Die Harze und die Harzbehälter, Vol. II.

PITS

All wood elements when first formed are limited by a very thin cellulose membrane, the *primary wall*. Subsequent development involves an internal thickening which is composed very largely of lignin, the *secondary wall*. This thickening may proceed uniformly, or, as is usually the case, small gaps, called *pits*, occur. A pit is merely an unthickened portion of the cell wall. Pits are of two principal types, *simple* and *bordered* (Fig. 11).


FIG. 9.—Tangential section of a fusiform ray from *Pinus ponderosa* (western yellow pine); *r. d.*, horizontal resin duct; *e.*, epithelial cells; *r. t.*, ray tracheids; the remainder of the cells are ray-parenchyma cells. Magnified about 200 diameters.

Intermediate forms exist whose reference to either group is arbitrary.

A simple pit is one in which the thickening about a spot on the primary wall forms a *canal* which is equally wide throughout its length, or narrowing outward (Fig. 11, *H*). The length of the canal is determined by the thickness of the secondary wall. When simple pits occur in very thick-walled cells, there is often a tendency to a slight funnel-formed enlargement of the canal toward

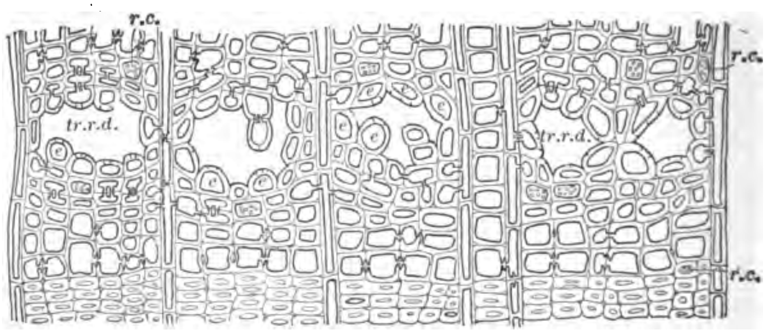


FIG. 10.—Cross section of a wound area in *Tsuga canadensis* (eastern hemlock) showing five traumatic resin ducts (*tr. r. d.*), in tangential row. Note thick-walled epithelial cells (*e*), and occasional resin cells (*r. c.*), showing sieve-like end walls. Magnified about 150 diameters.

the primary wall. Often the canal widens sufficiently to present the appearance of a narrow border (Fig. 11, *G*). Seen in profile, as in section, the pit canal of such a pit is narrow at the end toward the centre of the cell, but widens gradually outward.

A bordered pit is one in which the canal widens suddenly, that is, with a distinct angle, toward the primary wall (Fig. 11, *A*). In surface view a bordered pit appears as a bright spot or slit within a circle or ellipse (Fig. 11, *B*). This outer circle marks the limit of the unthickened area; the bright spot is the inner opening or *aperture* of the canal; the zone between the two is called the *border*.

Pits, especially bordered ones, usually are paired on opposite sides of the primary-cell walls. Pits between vascular elements are invariably bordered; between parenchymatous elements, invariably simple; between vascular and parenchymatous, they may be simple, but more frequently are *semi-bordered*, that is,

bordered in the vessel or tracheid, and simple in the adjacent parenchyma cells (Fig. 11, *F*). Pits in typical wood fibres are simple and slit-like, and usually in oblique position (Figs. 11, *K;* 2, *B*). In many cases, however, where the fibres resemble tracheids their pits are more or less bordered. The fibres of the bast have only simple pits.

The shape of the border is commonly circular, but may be oval, lenticular, oblong, or, in the case of dense aggregation, polygonal. *Scalariform markings* found on the vessel walls in certain

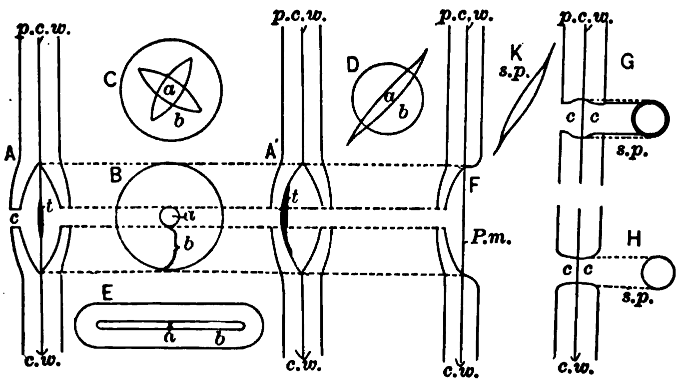


FIG. 11.—Schematic representation of pits, greatly enlarged. *A*, section of bordered pit showing cell walls (*c. w.*), primary cell wall (*p. c. w.*), pit canal (*c*), torus (*t*); *A'*, the same with torus (*t*) shoved to one side and lying lid-like against the aperture of the pit canal; *B*, surface view of bordered pit shown in *A* or *A'*, showing aperture (*a*) and border (*b*); *C*, surface view of bordered pit with lenticular aperture (*a*), the crossed appearance being due to the fact that the apertures on opposite sides of the pit are shown; *D*, surface view of a bordered pit with slit-like aperture (*a*), common in thick-walled tracheids of late wood in gymnospermous woods; *E*, surface view of scalariform bordered pit with narrow, elongated aperture (*a*) and border (*b*); *F*, section of a semi-bordered pit showing border on one side only; *G*, simple pit with funnel-formed canal and appearing slightly bordered in surface view; *H*, ordinary simple pit with canal (*c*) uniform or narrowing outward (*i.e.*, toward primary cell wall); *K*, surface view of slit-like pit common in wood fibres.

woods (*i.e.*, *Magnolia* [Plate VI, Fig. 3], *Anona glabra*, *Liquidambar* in part) are merely much-elongated bordered pits which appear as horizontal clefts with only narrow portions of the wall between them (Fig. 11, *E*).

The pit cavities of two adjacent pits are separated by the primary walls which persist as a *limiting membrane* (Fig. 11, *p.m.*).

This membrane, which is really made up of two membranes of contiguous cells which have become united in development, is very thin toward the border of the pit, but usually thickened near the centre. This thickened portion is called the *torus* (Fig. 11, *t*). The pit membrane very frequently increases in size and bulges out so that the torus lies lid-like against the aperture of the pit canal (Fig. 11, *A'*). A sieve-like structure of the pit membranes has been observed in the bordered pits of the vessels in certain species.*

Between the bordered pits on the radial walls of the tracheids of Gymnosperms it is very common to find folds of cellulose, which, when properly stained, are quite conspicuous under the compound microscope. These folds, which appear as horizontal or more or less semi-circular markings, sometimes doubled, are most abundant in the thin-walled tracheids of the early wood. They are without diagnostic value.

The apparent function of pits is to facilitate the passage of some part of the cell contents from one cell to another. Bordered pits are mostly associated with water transfer, and simple pits with the distribution of elaborated food.

Pits are of considerable value for systematic purposes. For example, in the white pines and *Pinus resinosa,* the radial wall of each ray-parenchyma cell shows one or two large simple pits communicating with each adjacent wood tracheid, while in the foxtail and nut pines and in the hard pines there are three to six rather small pits so communicating (Figs. 4–7). The presence of pits in the tangential walls of the tracheids of the late wood in soft pines, and their absence in similar location in the pitch pines, serve as an additional point of distinction between these two great groups.

While the pits in the radial walls of the tracheids of Gymnosperms are usually in a single row, they may occur in biseriate or triseriate arrangement. In the larger tracheids of *Tsuga* they are mostly biseriate. In *Taxodium distichum* they are characteristically crowded, flattened, and often irregularly arranged.

In dicotyledonous woods as a whole, pits are much smaller and less regular in their distribution than in Gymnosperms. The

* JÖNSSON, BENGT.: Siebähnliche Poren in den trachealen Xylemelementen der Phanerogamen, hauptsächlich der Leguminosen, Berichte d. deutschen Botanischen Gesellschaft, Vol. X, 1892, pp. 494–513.

nature of the pits, whether simple or distinctly bordered, in the walls of the wood fibres, and the character of pitting where vessels are in contact with wood parenchyma or the rays, are often helpful in classification. Scalariform bordered pits in the walls of the vessels of *Magnolia* (Plate VI, Fig. 3) serve to distinguish this genus from *Liriodendron* (Plate VI, Fig. 4), in which they are absent or very sparingly developed.

*References*

DEBARY, A.: Comparative Anatomy, pp. 158–164.

GREGORY, E. L.: The Pores [Pits] of the Libriform Tissue, Bul. Torrey Bot. Club, N. Y., Vol. XIII, 1886, pp. 197–204; 233–244.

PENHALLOW, D. P.: North American Gymnosperms, pp. 59–77.

SOLEREDER, H.: Anatomy of the Dicotyledons, Vol. II, pp. 1139–41.

GERRY, ELOISE: The Distribution of the "Bars of Sanio" in the Coniferales, Annals of Botany, Vol. XXIV, No. 93, January 1910, pp. 119–123.

KREUZ, J.: Die gehöften Tüpfel des Xylems der Laub- und Nadelhölzer, Sitzb. d. Akad. Wiss., Wien, Vol. LXXVI, Part. 1, 1878, pp. 353–384.

RUSSOW, E.: Zur Kenntnis des Holzes, insonderheit des Coniferenholzes, Bot. Centralblatt, Vol. XIII, Nos. 1–5, 1883.

## TYLOSES

It is not uncommon to find the vessels of many Dicotyledons (Plate III, Figs. 3, 4) and the resin ducts of certain Gymnosperms more or less completely filled with pith-like cells called *tyloses.* Usually the walls of the tyloses are very thin, but exceptions occur (*e.g., Robinia* and *Toxylon*) where they may be considerably thickened, sometimes becoming sclerotic. Tyloses in large vessels are plainly visible to the unaided eye, their high lustre giving them the appearance of froth.

Tyloses are cells which have developed from protrusions of the wood or ray parenchyma into the lumen of a vessel or the canal of a duct or an intercellular space. Their formation is apparently due to differences in pressure within the parenchyma cells and the vessels or ducts they adjoin. After vessels lose their sap they are no longer turgid, in fact the air within them becomes rarefied. In consequence of this reduction of pressure the neighboring parenchyma cells rupture or disorganize the limiting membranes of the pits, thereby rendering the lumen of the vessel available for their further extension and development. This explains why tyloses do not occur in vessels which are in a state of activity, but as a

general rule arise in the inner region of the sapwood, *i.e.*, in the wood where the vessels are losing their power of conduction. Once inside the vessel, the intruding cells rapidly divide and grow until the space is filled or their food-supply is exhausted, and thus form a parenchymatous tissue in which carbohydrates may be stored.

The effect of the formation of tyloses is to block up the vessels and render the heartwood impervious, or nearly so, to the entrance of fluids. Tyloses are especially abundant in the vessels of white oaks (*Frontispiece*), thus adding to the technical value of the wood for cooperage. This feature is also of some value in separating the white from the black oaks, since in the latter group tyloses are rather scarce or wanting (Plate II, Fig. 6). In *Quercus marilandica*, however, tyloses are abundant.

Tyloses also occur occasionally in the tracheids of the wood of Gymnosperms, particularly in the wood of the roots. Tyloses in resin ducts are characteristic of *Pinus* and (in less degree) *Picea*, but are sparingly developed or absent in *Larix* and *Pseudotsuga*.

*References*

KIRSCH, SIMON: On the Development and Function of Certain Structures in the Stipe and Rhizome of *Pteris aquilina* and Other Pteridophytes, Trans. Royal Soc. of Canada, 3d Series, Vol. I, sec. iv, Ottawa, 1908, pp. 403–8.

DEBARY, A.: Comparative Anatomy, p. 170.

SACHS, JULIUS: Lectures on the Physiology of Plants (trans. by H. Marshal Ward), p. 581.

CHRYSLER, M. A.: Tyloses in Tracheids of Conifers, New Phytologist, No. 7, 1908, pp. 198–204.

GOLDEN, K. E.: Tyloses in Brosimum aubletii, Proc. Ind. Acad. Sci., 1904, pp. 227–232.

VON ALTEN, H.: Kritische Bemerkungen und neue Ansichten über die Thyllen, Bot. Zeitung, Vol. LXVII, 1909, pp. 1–23.

RAATZ, WILHELM: Ueber Thyllenbildungen in den Tracheiden der Coniferenhölzer, Ber. d. deutschen Bot. Gesellschaft, Vol. X, 1892, pp. 183–192.

## PITH FLECKS OR MEDULLARY SPOTS

*Pith flecks* or *medullary spots* are small, brown or grayish, half-moon-shaped patches appearing so commonly on the cross sections of many diffuse-porous woods, especially of the four families *Salicaceæ*, *Betulaceæ*, *Rosaceæ*, and *Aceraceæ*. On longi-

tudinal sections of a stem the pith flecks appear as flattened strands running up and down the stem, and often into the root. Examined microscopically, pith flecks are seen to be made up of irregularly shaped, polyhedral, parenchymatous cells with thick, dark-colored walls copiously pitted with simple pits. At certain seasons the cells are filled with starch grains.

Pith flecks have a pathological origin. They are due to the work of cambium miners whose tunnels are filled by the tylosal development of adjacent uninjured parenchyma cells, especially of the cortex. The dissolved cell fragments and larval excrement are pressed into a narrow border by the rapid growth and division of the "filling cells."

This feature has frequently been used for purposes of classification, principally because of the failure to understand its exact nature. It has been noted in a large number of woods, but is by no means constant in its occurrence. Some stems, for example, contain numerous pith flecks, while other individuals of the same species in the vicinity, or even from the same root stock, do not show them. Furthermore, in stems with pith flecks certain growth rings may be free of them, while others of the same section are thickly dotted, or the lower portion of the stem may contain them and the upper be entirely free.

Taken in connection with other features, however, the presence of pith flecks in abundance may serve to indicate the species. For example, they are usually very numerous in *Betula populifolia* and *B. papyrifera*, and infrequent in *B. lenta*, *B. lutea*, and *B. nigra*, numerous in *Acer rubrum* and *A. saccharinum*, but usually wanting in *A. saccharum*.

*References*

RECORD, S. J.: Pith Flecks or Medullary Spots in Wood, Forestry Quarterly, Vol. IX, No. 3, 1911, pp. 244–252.

GROSSENBACHER, J. G.: Medullary Spots: A Contribution to the Life History of Cambium Miners, Tech. Bul. No. 15, N. Y. Agri. Exp. Sta., Geneva, N. Y., 1910.

VON TUBEUF, KARL F.: Die Zellgänge der Birke und anderer Laubhölzer, Forstlich-naturw. Zeitschrift, VI. Jahrgang, 1897, pp. 314–319. Also Naturw. Zeitschrift f. Forst- und Landwirtschaft, 6. Jahrgang, 1908, pp. 235–241.

KIENITZ, M.: Die Entstehung der "Markflecke," Bot. Centralblatt, Vol. XIV, 1883, pp. 21–26; 56–61.

### BARS OF SANIO

In radial and cross sections of the wood of all Gymnosperms it is not uncommon to find small bars stretched across the lumina of the tracheids from one tangential wall to another. Occasionally they appear in isolated tracheids, but usually traverse in the same direction the entire length of a long radial series (Fig. 12). While the most common form of bar is a simple cylinder slightly enlarged at the points of contact with the cell wall, they may occur as

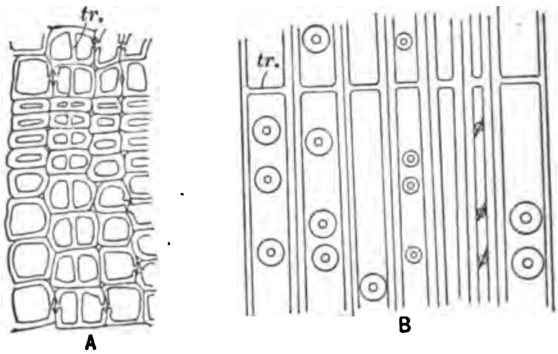


FIG. 12.—Bars of Sanio in *Pinus murrayana* (lodgepole pine). *A*, cross section showing tracheids with bars (*tr.*) crossing the middle row in tangential series; *B*, radial section showing bars (*tr.*) which become wider in late wood. Magnified about 150 diameters.

double bars or as constricted plates. These bars, which were first described by Sanio (*loc. cit.*), originate in the cambium and result from the partial resorption of folds in the cell wall. Their function is unknown. Owing to their general distribution throughout all species of Gymnosperms they are without taxonomic value.

*References*

SANIO, CARL: Botanische Zeitung, Vol. XXI, No. 14, 1863, p. 117.

MÜLLER, CARL: Ueber die Balken in den Holzelementen der Coniferen, Bericht ü. d. Verhandlungen d. achten General-Versammlungen d. deutschen Botanischen Gesellschaft, 1890, pp. (17) to (46).

RAATZ, WILHELM: Die Stabbildungen in secundären Holzkörper der Bäume und die Initialentheorie, Jahrb. für Wissenschaftliche Botanik, Vol. XXIII, 1892, pp. 567–636.

### TIER-LIKE ARRANGEMENT OF ELEMENTS

There are numerous woods which present on longitudinal section (particularly the tangential) fine, delicate cross lines or stripes sometimes called "ripple marks." The distance between these markings varies from 0.11 to 0.50 mm., and is fairly constant for a species. On some woods (*e.g.*, *Æsculus octandra*, *Swietenia mahagoni*, and *Diospyros virginiana* [Plate IV, Figs. 4, 5]), these lines are very clear and distinct to the unaided eye; on others (*e.g.*, *Tilia americana*, *T. pubescens*, and *T. heterophylla*) they are near the limit of vision, or again, they are invisible without the lens. In most species showing these markings the feature is constant and of considerable importance for diagnostic purposes, though in a few species (*e.g.*, *Swietenia mahagoni*) the same piece of wood may show the markings in one place and not in another.

This cross-striping of a wood is due (1) to the arrangement of the rays in horizontal series, or (2) to the tier-like ranking of the wood fibres, vessel segments, or other elements, or (3) to a combination of (1) and (2) (Plate IV, Figs. 4, 5). The lines resulting from the horizontal seriation of the rays is usually more conspicuous and of more common occurrence than those in (2). In the combination of the two forms, which is very common, the junction of the vessel segments or of the fibres is usually between the rays (Plate IV, Fig. 5).

This peculiar arrangement of wood elements is also evidenced on cross section. Where the rays are in perfect horizontal seriation a section between two tiers shows an entire absence of rays. In most instances, however, it results in gaps of irregular width, depending upon the regularity of the stories. Where the rays are much wider near the middle than at the margin, their apparent width when viewed transversely will show considerable variation, according to the relative location of the plane of section. Where the fibres are arranged in tiers, their apparent size is affected in a similar manner.

*References*

RECORD, S. J.: Tier-like Arrangement of the Elements of Certain Woods, Science, January 12, 1912, pp. 75–77.

VON HÖHNEL, FRANZ RITTER: Ueber stockwerkartig aufgebaute Holzkörper. Sitzb. d. Math. Naturw. Classe d. kaiserlichen Akademie d. Wissenschaften, Vol. LXXXIX, Part 1, Wien, 1884, pp. 30–47.

Von Höhnel, Franz Ritter: Ueber den etagenformigen Aufbau einiger Holzkörper, Berichte d. deutschen Bot. Gesellschaft, Vol. II, Berlin, 1884, pp. 2-5.

## GROWTH RINGS

A tree increases in diameter by the formation between the old wood and the inner bark of new woody layers which envelop the entire stem and living branches. In cross section, as on the end of a log, these layers appear as concentric zones or rings (Fig. 1). The distinction between contiguous rings is due to structural peculiarities, augmented in some instances by local deposit of resin or pigment. Each ring consists of two more or less readily distinguishable parts, the inner, called *early wood* (spring wood), and the outer, or *late wood* (summer or autumn wood).

In *ring-porous* woods (*Frontispiece;* Plate III), such as *Quercus, Castanea, Fraxinus,* and *Robinia,* the larger vessels become localized in the early wood, thus forming a region of more or less open and porous tissue, while the wood fibres preponderate in the late wood, thereby producing a much denser layer. In other instances, as in *Acer, Magnolia, Æsculus,* and *Liquidambar* (Plate VI), where the vessels are fairly uniformly distributed—diffuse-porous—the occurrence of growth rings may be due to one or more of the following conditions: (1) a gradual diminution in size of the vessels toward the periphery of the ring; (2) a decided reduction in number of the vessels in the late wood; (3) a change in kind of the wood elements, *e.g.*, where the outer layer of late wood consists wholly or chiefly of wood parenchyma or of tracheids; (4) increase in thickness of the wall of the wood elements near the limit of the late wood.

In Gymnosperms where vessels are wholly absent growth rings are due to variations in the tracheids. Viewed in cross section the cells of early wood are relatively large, thin-walled, and more loosely aggregated; while those of the late wood are smaller, thicker-walled, closely packed together and very often radially flattened, presumably as a result of cortical pressure (Fig. 8; Plate II, Figs. 1,2,4). This transition from open to dense structure may be gradual, as in the soft pines, or very abrupt, as in many hard pines. Not infrequently the dense aggregation of cells involves a deepening of the color peculiar to the tissue as a whole. In any wood it is almost invariably the apposition of the more open

early wood to the face of the more compact late wood that serves to define the zones of growth.

The origin of growth rings is physiological. Plants, like animals, seem incapable of indefinitely sustained activity, but require periods of recuperation. In latitudes of decided seasonal changes such periods of rest are provided by the alternation of the seasons, in which case the zones of growth correspond very closely with annual periods. This constancy of relation diminishes towards the equator and, although in the tropics growth rings are not uncommon, they provide no reliable index to the age of the tree. In temperate climates trees occasionally produce *secondary* or *false* rings, usually attributable to some disturbance of the normal course of growth of the season, such as the action of frost, drought, hail, and insect damages. Such rings, however, can usually be distinguished from annual rings by their less pronounced line of demarcation.

Variation in width of different growth rings is common to all trees, and is determined by external conditions of light, heat, moisture, and available food-supply. The cross section of a stem presents in the variable form and size of its rings a history of its growth and nutrition.

The breadth of an individual growth ring may not be uniform all round in consequence of unequal acceleration of the growth on different sides, the ring thus becoming undulating or eccentric. The growth centre is accordingly not coincident with the geometric centre. The more nearly erect the stem and the more nearly perfect the crown, the more closely will the two centres coincide. In some species (*e.g., Carpinus caroliniana* and *Juniperus virginiana*), irregularity of growth causes the trunks to become fluted or even deeply scalloped.

The growth rings near the centre of a stem usually exhibit considerable difference in structure from those later formed. The elements are usually thinner-walled, of shorter length, and less densely aggregated, so that the inner core of wood is comparatively soft and weak. In the wood of Dicotyledons, although the elements characteristic of the species are all present, their characteristic arrangement does not appear clearly until later. This is particularly evident in the distribution of the vessels and wood parenchyma in many woods. Consequently, in the employment of these features for systematic purposes, it is important to use stems of considerable thickness rather than small branches or young shoots.

In ring-porous woods of good growth it is usually the middle portion of the ring in which the thick-walled, strength-giving fibres are most abundant. As the breadth of the ring diminishes, this middle portion is reduced so that very slow growth (fine grain) produces comparatively light, porous wood composed

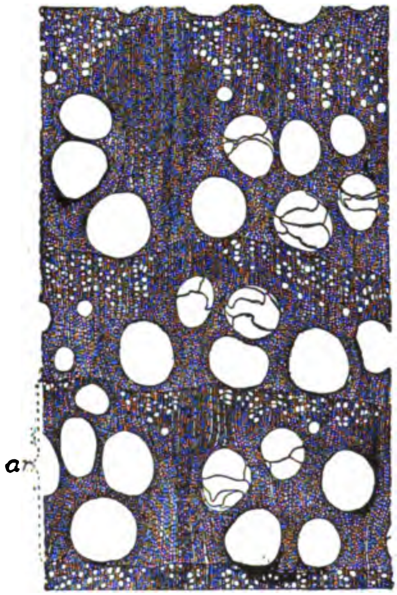

FIG. 13.

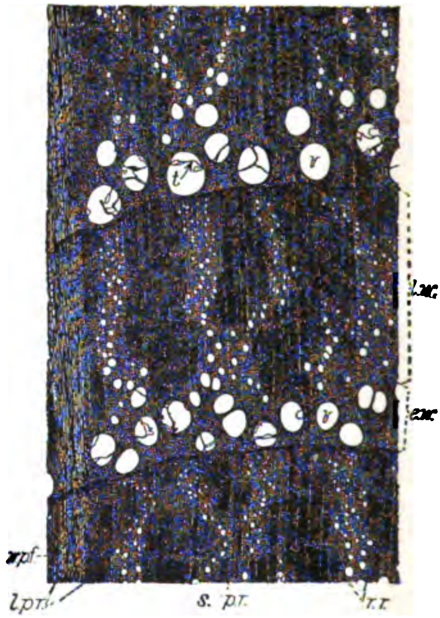

FIG. 14.

FIG. 13.—*Quercus macrocarpa* (bur oak): cross section through three entire growth rings showing very large pores in early wood and general absence of dense-walled wood fibres. Such wood is light, soft, and not strong. Magnified 20 diameters. (From Bul. 102, U. S. Forest Service.)

FIG. 14.—*Quercus macrocarpa* (bur oak): cross section through one entire growth ring and parts of two others, showing comparatively small pores (*v*) in early wood (*e. w.*), and presence of abundant thick-walled wood fibres in the late wood (*l. w.*). Such wood is heavy, hard, and strong. Magnified 20 diameters. (From Bul. 102, U. S. Forest Service.)

mostly of thin-walled vessels and wood parenchyma (Figs. 13, 14). This explains why "second-growth" (*i.e.*, rapidly grown) hickory, ash, and chestnut are stronger than the slowly grown "virgin" stock of the same species. Moreover, in trees of this type there is less early wood formed at the base of a stem than farther up,

because growth begins considerably later at the base. The strongest, densest, and toughest timber is that grown in the open where conditions are favorable to rapid growth.

In diffuse-porous woods, such as *Acer*, *Betula*, *Liriodendron*, and *Fagus*, there seems to be no definite relation between ring width and density. In Gymnosperms, as a rule, wood of medium to fine grain contains a greater proportion of late wood and consequently possesses greater weight and strength than when very fine or very coarse grained.

In this connection the following statement of H. Mayr * is interesting: "Assuming identity of soil, the specific weight and hardness of wood decreases with distance from the optimum climate of its production both toward cooler or warmer climates. It is indifferent whether the annual zones consequently increase or decrease in breadth, or whether the wood is broadleaved or coniferous. Within the natural habitat of any tree the centre of its habitat produces the heaviest and hardest wood."

Various theories have been advanced to explain the formation of early and late wood. Penhallow (following Sachs†) says that the elements of the early wood are "formed under a minimum tension in consequence of which they rapidly attain to relatively great size, and it is therefore found that the first tissue of the season is always most open. In consequence of the great excess of nutrition supplied during this period of growth, and the very rapid process of construction which follows, secondary growth of the walls is limited, and these structures remain thin, while the lumens are correspondingly large."

R. Hartig maintains that the thin-walled early wood is due to poorer nutrition and the necessity of forming conductive tissue, while thick-walled late wood results from better nutriment during the warm and sufficiently moist summer. Wieler, on the other hand, claims that the more unfavorable the conditions of nutrition, the slower the development of assimilating organs, hence the more late wood.

*References*

PENHALLOW, D. P.: The Relation of Annual Rings to Age, Can. Records of Sci., Vol. I, p. 162.

————: North American Gymnosperms, pp. 24–32.

DEBARY, A.: Comparative Anatomy, pp. 475–478; 500–507.

* Schlich's Manual of Forestry, Vol. V, rev. ed., p. 54.

† Text-Book of Botany, p. 575, foot-note.

ROTH, FILIBERT: Timber, Bul. 10, U. S. Div. of Forestry, pp. 14–16.

ZON, RAPHAEL: Methods of Determining the Time of Year at which Timber was Cut, For. Quarterly, Vol. VIII, 1908.

BUCKHOUT, W. A.: The Formation of the Annual Ring of Wood in the European Larch and the White Pine, For. Quarterly, Vol. V, No. 3, Sept. 1907, pp. 259–267.

DACHEROWSKI, A.: Type and Variability in the Annual Wood Increment of Acer rubrum, L. Ohio Nat. 8, pp. 343–349, 1908.

NÖRDLINGER, H.: Die Holzringe als Grundlage des Baumkörpers, Stuttgart, 1872.

SANIO, CARL: Botanische Zeitung, Vol. XXI, No. 50, 1863, pp. 391–399.

HARTIG, R.: Lehrbuch der Anatomie und Physiologie der Pflanzen, pp. 261–263.

### HEARTWOOD AND SAPWOOD

The course of development of the various wood elements is fundamentally the same, viz., they are formed in the cambium, they increase in size, their walls thicken more or less, they function as living cells for a time, but eventually lose their protoplasmic contents and die. Their change from a living to a dead condition is ordinarily not followed by immediate decay, and the cells continue to perform the mechanical function of support. The parenchyma cells remain alive for a longer time than the other elements.

The outer layers of growth of a tree, especially one of considerable thickness, contain the only living elements of the wood and comprise the *sapwood*. There is usually a sharp line of demarcation between the living elements of the sapwood and the non-living elements of the *heartwood*, though the vigor of the living cells gradually wanes as their distance from the cambium increases. The thickness of sapwood varies widely in different species, in different individuals, in different portions of a single tree, and often on different radii of any particular section. Thin sapwood is characteristic of certain genera, for example *Catalpa*, *Robinia*, *Toxylon*, *Sassafras*, *Morus*, *Gymnocladus*, *Juniperus*, and *Taxus*, while in others such as *Hicoria*, *Acer*, *Fraxinus*, *Celtis*, and *Fagus*, thick sapwood is the rule.

The fact that sapwood occupies the peripheral layers of the stem causes it to form a considerable proportion of the volume. The percentage of sapwood to total volume of the stem is for certain species approximately as follows: *Pinus palustris*, 40;

*P. heterophylla*, 50; *P. tæda*, 55; *P. strobus*, 30; *Tilia americana*, 65; *Juniperus virginiana*, 25; *Liriodendron tulipifera*, 20; *Quercus alba*, 20; *Robinia pseudacacia*, 12.

In the same species there generally exists a constant relation between the crown space and the cross-sectional area of the sapwood in the stem. Rapidly growing trees and trees in the open have a larger proportion of sapwood than those of the same species growing in less open stands. In the latter case the number of rings in the sapwood is almost always greater.

Heartwood in general is of a darker color than sapwood, due to the presence of gums, resins, and other substances. In some genera, however, there is little difference in appearance between these two portions, for example, in *Nyssa*, *Ilex*, *Celtis*, *Populus*, *Salix*, *Picea*, *Abies*, and *Tsuga*.

Change from sapwood to heartwood is never accompanied by increased lignification. Deposition of large amounts of gum or resin materially increases the weight of the wood, and on that account in certain tropical species the heartwood averages fully one-third heavier than the sapwood.

While physiologically heartwood is that portion of the woody cylinder which does not contain living elements, yet technically only discolored parts are so called, though it of course is without living elements. Branches form heartwood as soon as they cease to grow vigorously, no matter in what part of the crown they are located. In a whorl one branch may be practically all heartwood while none of the others shows any.

Usually heartwood is commercially more valuable than sapwood, partly on account of its color, but more especially because of its greater durability under exposure. In grading lumber sapwood is often considered a defect. Important exceptions are found in the use of paper birch for spools, hickory and ash for handles, spokes, etc., woods for manufacture of pulp, and timber to be impregnated with preservatives, where heartwood is considered undesirable.

The average thickness of the sapwood and the character of the demarcation between heartwood and sapwood are features frequently made use of in classification.

*References*

Roth, F.: Timber, Bul. 10, U. S. Div. of Forestry, p. 13.

Boulger, G. S.: Wood, p. 17.

DEBARY, A.: Comparative Anatomy, pp. 507–511.
MÜNCH, ERNST: Ueber krankhafte Kernbildung, Naturw. Zeitschrift für Forst- und Landwirtschaft, 8. Jahrgang, 1910, pp. 533–547; 553–569.
NÖRDLINGER, H.: Die Technischen Eigenschaften der Hölzer, Stuttgart, 1860, pp. 28–40.

## GRAIN AND TEXTURE

*Grain* is a general term used in reference to the arrangement or direction of the wood elements and to the relative width of the growth rings. To have specific meaning it is essential that it be qualified. The kinds of grain commonly described are *fine, coarse, even, uneven, rough, smooth, straight, cross, spiral, twisted, wavy, curly, mottled, landscape, bird's-eye, gnarly,* and *silver.*

*Coarse grain* applies to woods of rapid growth, *i.e.*, it denotes wide rings; *fine grain,* to woods of slow growth. *Even* and *uneven* apply respectively to regularity or irregularity of the growth rings; *rough* and *smooth,* to the manner in which wood works under tools. *Straight grain,* as applied to a tree, occurs when the wood elements are parallel to the axis of growth; as applied to a board, when the radial and tangential planes of structure are parallel to its length. Sawn boards or timbers are often *cross-grained* even when cut from *straight-grained* logs while *straight-grained* pieces may be split from *spiral-grained* trees. The strength of a piece of timber, particularly in bending, rapidly weakens as the plane of its fibres deviates from a direction parallel to its length. On this account split timber is usually stronger than when sawn, a fact made use of in wood-working. For instance, billets for handles and blocks for telegraph-insulator pegs are invariably split.

It is not uncommon in any tree, and usual in many cases, for the wood elements to be arranged spirally about the central axis. The spiral may run to the right or left, but the direction is usually fairly constant within a species. Various theories have been advanced to explain the phenomenon of spiral growth or torsion. The one most commonly accepted considers the obliquity of the fibres a method of accommodating the increase in length of the cells after their formation in the cambium. There seems to be ground for suspecting that wind may have an influence on this spiral development. For instance, trees of *Larix americana* have been observed which, though straight-grained while young, had

developed spirally twisted growth layers after the trees were thirty to forty years old, when, unprotected by associated trees, they were subjected to heavy winds. There is a further possibility that some species have an inherent tendency to develop twisted stems. In any event, when such stems are sawn the lumber is cross-grained and usually unfit for use where strength is required. The extent of the defect depends upon the pitch of the spiral.

When the elements interweave and are not constant in one general direction, wood is also said to be *cross-grained,* though the term *spiral grain* or *interlocked grain* is more applicable. Often this condition does not interfere with tangential splitting. Wood with interlocked fibres is tough and not necessarily weakened, but always tends to warp and twist in seasoning. Examples occur in *Nyssa, Æsculus, Liquidambar,* and *Eucalyptus.*

*Wavy grain* and *curly grain* result when the fibres undulate but do not cross each other. When the undulations are large the grain is said to be *wavy;* when small, *curly.* Usually the waves are on the radial plane and tangential splitting produces a smooth surface, showing the grain to advantage. Such grain is common in *Acer, Æsculus, Fraxinus, Prunus,* and *Betula.* It is most common near the roots and at the insertion of large branches.

*Silver grain* is produced by quarter-sawing timber in which the rays are sufficiently high to show readily on radial surface. The appearance of the rays adds very materially to the value of woods for cabinet work and furniture. Species which exhibit conspicuous silver grain are *Quercus* (all species, but particularly *Q. alba*), *Platanus occidentalis, Fagus americana,* and to a less extent *Acer saccharum, Prunus serotina,* and *Swietenia mahagoni.*

*Texture* is a term which refers to the relative size, quality, or fineness of the elements as affecting the structural properties of a wood. Like *grain,* it requires qualifying adjectives to attain specific meaning. The most common attributes of texture are fineness and coarseness, evenness and unevenness. *Coarse texture* applies to woods with many large elements, or the average size of which is large, for example, *Castanea, Gymnocladus, Sequoia.* In *fine texture* the opposite condition prevails, as in *Juniperus, Æsculus, Salix, Populus.*

*Even texture* or *uniform texture* are terms used to describe woods whose elements exhibit little variation in size, for example, *Taxodium* (Plate II, Fig. 1), *Juniperus* (Plate II, Figs. 3, 4), *Sequoia, Æsculus* (Plate VI, Fig. 5). *Uneven texture* applies to

the opposite condition, such as is common in all prominently ring-porous woods (Frontispiece; Plate III), (*e.g.*, *Quercus*, *Castanea*, *Ulmus*, *Fraxinus*), and in other woods with decided differences between early and late wood (*e.g.*, *Pinus palustris*, *P. tæda*, and *Pseudotsuga*).

Texture and grain are terms very commonly confused in popular usage. The distinctions as above expressed will obviate the difficulty resulting from the attempt to make the term "grain" too comprehensive.

*Reference*

RECORD, S. J.: Grain and Texture in Wood, Forestry Quarterly, Vol. IX, No. 1, 1911, pp. 22–25 (reprinted in Woodcraft, June 1911).

## KNOTS

Branches originate, as a rule, at the central axis of a stem and, while living, increase in size by the addition from year to year of woody layers which are a continuation of those in the stem. From this it follows that the form of the included portion or *knot* approaches that of a cone with its apex inward.

During the development of a tree most of the limbs, especially the lower ones, die, but persist for a time—often for a great many years. Subsequent layers of growth of the stem are not intimately joined with the fibres of the dead limb, but are laid around its base. Hence dead branches produce *loose knots* which may drop out after the tree has been cut into lumber.

The stubs of dead limbs that have broken off are usually occluded by subsequent growth so that the outer surface of the bole is smooth or clear, especially toward the butt. The interior of all stems is more or less knotty, but in butt logs the knots are fewest and smallest. Sometimes knots enhance the value of timber for cabinet work and interior finish, by giving it a pleasing figure. Material cut near the junction of a large limb or at the base of a crotch usually exhibits very handsome grain.

Knots materially affect checking and warping, ease in working, and cleavability of timber. They are defects which weaken timber and depreciate its value for structural purposes where strength is an important consideration. The weakening effect is much more serious where timber is subjected to bending and tension than where under compression. The extent to which a knot affects the strength of a beam depends upon its position, size, direction

of fibre, and condition. A knot on the upper side is compressed, while one on the lower side is subjected to tension. The knot, especially (as is often the case) if there is a season check in it, offers little resistance to tensile stress. Small knots, however, may be so located in a beam as actually to increase its strength by tending to prevent longitudinal shearing. Knots in a board or plank are least injurious when they extend through it at right angles to its broadest surface. Knots apparently have little effect on the stiffness of timber.

"At the junction of limb and stem the fibers on the upper and lower sides of the limb behave differently. On the lower side they run from the stem into the limb, forming an uninterrupted strand or tissue and a perfect union. On the upper side the fibers bend aside, are not continuous into the limb, and hence the connection is imperfect.

"Owing to the arrangement of the fibers, the cleft made in the splitting never runs into the knot if started on the side above the limb, but is apt to enter the knot if started below, a fact well understood in woodcraft." *

*Sound knots* are as hard as, and usually considerably harder than, the wood surrounding them. In coniferous woods they are commonly highly resinous, and in finished lumber are apt, on that account, to fail to retain paint or varnish. When such trees decay the knots remain sound and are prized for fuel. In grading lumber and structural timber, knots are classified according to their character (*sound, loose, encased*), size (*pin, standard, large*), and direction of fibre (*round, spike*).

*References*

ROTH, FILIBERT: Timber, Bul. 10, U. S. Div. For., 1859, pp. 23, 41, 44 48, 49.

CLINE, McGARVEY, and KNAPP, J. B.: Properties and Uses of Douglas Fir, Bul. 88, U. S. Forest Service, 1911, pp. 32–37.

### DENSITY AND WEIGHT

Density of wood varies widely in different species, in different individuals, and even in different portions of the same tree. The specific gravity † of wood substance is about 1.6; hence the

* Roth, *loc. cit.*, p. 23.

† By specific gravity is meant the ratio of the weight of thoroughly dried

reason any wood floats in water is because of the buoyancy of the air imprisoned in its elements and spaces. When this air is displaced by water the wood becomes "waterlogged," and will no longer float. The greater the proportion of cell wall the greater the density; consequently late wood is denser and of higher specific gravity than early wood, and the greater the proportion of late wood the denser the wood as a whole. Woods composed largely of thick-walled, narrow-lumined fibres are always dense and heavy. Other things being equal, the weight of wood is a good criterion of its hardness and strength.

In practice the weight of wood is calculated from small, sound specimens which have been oven-dried at a temperature of 100° C. (the boiling-point of water) until they reach a constant weight. Since weight is subject to wide variations, the single value usually assigned to a species is really the average of a large number of determinations and is applicable only in a general way. If a wood weighs less than thirty pounds per cubic foot it is considered light; if between thirty and forty pounds, medium light or medium heavy; and if more than forty pounds, heavy.

The lightest wood in the United States is that of *Leitneria floridana,* the specific gravity of which is 0.21 for body wood and 0.15 for root wood. The wood of *Condalia ferrea* has a specific gravity of 1.3; that of *Guaiacum sanctum* 1.14. From the investigation of 429 American species, as published in the report of the Tenth Census of the United States, it appears that 242 species, including most of the commercial woods, lie between 0.45 and 0.75 in specific gravity.

TABLE III

ONE HUNDRED AND FIFTY TREES OF THE UNITED STATES ARRANGED IN ORDER OF THE AVERAGE SPECIFIC GRAVITY OF THEIR DRY WOODS (TENTH CENSUS).

| *Species* | *Sp. Gr.* | *Species* | *Sp. Gr.* |
|---|---|---|---|
| Condalia ferrea | 1.30 | Quercus prinoides | .86 |
| Guaiacum sanctum | 1.14 | Quercus chrysolepis | .85 |
| Quercus virens | .95 | Hicoria alba | .84 |
| Quercus texana | .91 | Ostrya virginiana | .83 |

wood to an equal volume of water at its greatest density, which occurs at a temperature of 4° C. (39.2° F.). A cubic foot of pure water at this temperature weighs 62.43 pounds. Dividing the weight in pounds of a cubic foot of wood by 62.43 will give the specific gravity of the wood.

TABLE III—CONTINUED

| *Species* | *Sp. Gr.* | *Species* | *Sp. Gr.* |
|---|---|---|---|
| Quercus agrifolia | .83 | Quercus rubra | .65 |
| Hicoria glabra | .82 | Ulmus americana | .65 |
| Cornus florida | .82 | Taxus brevifolia | .64 |
| Hicoria laciniosa | .81 | Pinus edulis | .64 |
| Quercus michauxii | .80 | Magnolia grandiflora | .64 |
| Hicoria myristicæformis | .80 | Nyssa sylvatica | .64 |
| Pinus serotina | .79 | Taxus floridana | .63 |
| Diospyros virginiana | .79 | Cupressus macrocarpa | .63 |
| Toxylon pomiferum | .77 | Fraxinus pennsylvanica | .63 |
| Quercus laurifolia | .77 | Larix americana | .62 |
| Prosopis juliflora | .77 | Acer rubrum | .62 |
| Betula lenta | .76 | Juglans nigra | .61 |
| Quercus imbricaria | .75 | Pinus echinata | .61 |
| Pinus heterophylla | .75 | Betula papyrifera | .60 |
| Quercus prinus | .75 | Liquidambar styraciflua | .59 |
| Ulmus alata | .75 | Morus rubra | .59 |
| Quercus phellos | .75 | Castanea pumila | .59 |
| Quercus alba | .75 | Juniperus pachyphlœa | .58 |
| Quercus macrocarpa | .75 | Prunus serotina | .58 |
| Ilex decidua | .74 | Ilex opaca | .58 |
| Hicoria aquatica | .74 | Juniperus occidentalis | .58 |
| Larix occidentalis | .74 | Betula nigra | .58 |
| Quercus coccinea | .74 | Betula populifolia | .58 |
| Robinia pseudacacia | .73 | Fraxinus oregona | .57 |
| Quercus nigra | .73 | Platanus occidentalis | .57 |
| Celtis occidentalis | .73 | Pinus monophylla | .57 |
| Carpinus caroliniana | .73 | Castanopsis chrysophylla | .56 |
| Swietenia mahagoni | .73 | Pinus aristata | .56 |
| Ulmus racemosa | .73 | Juniperus utahensis | .55 |
| Ulmus crassifolia | .72 | Pyrus americana | .55 |
| Quercus aquatica | .72 | Pinus tæda | .54 |
| Prunus americana | .72 | Pinus balfouriana | .54 |
| Cratægus crus-galli | .72 | Magnolia macrophylla | .53 |
| Fraxinus quadrangulata | .72 | Pinus inops | .53 |
| Hicoria olivæformis | .72 | Pinus jeffreyi | .53 |
| Juniperus monosperma | .71 | Pseudotsuga taxifolia | .52 |
| Fraxinus lanceolata | .71 | Pinus rigida | .52 |
| Quercus velutina | .70 | Tumion taxifolium | .51 |
| Pinus palustris | .70 | Sassafras sassafras | .50 |
| Ulmus pubescens | .70 | Magnolia glauca | .50 |
| Quercus palustris | .69 | Æsculus californica | .50 |
| Gymnocladus dioicus | .69 | Juniperus virginiana | .49 |
| Acer saccharum | .69 | Pinus resinosa | .49 |
| Fagus americana | .69 | Alnus oregona | .48 |
| Gleditsia triacanthos | .67 | Chamæcyparis nootkatensis | .48 |
| Betula lutea | .66 | Tumion californicum | .48 |
| Fraxinus americana | .65 | Pinus ponderosa | .47 |

TABLE III—CONTINUED

| *Species* | *Sp. Gr.* | *Species* | *Sp. Gr.* |
|---|---|---|---|
| Abies magnifica | .47 | Pinus coulteri | .41 |
| Magnolia acuminata | .47 | Pinus murrayana | .41 |
| Populus grandidentata | .46 | Populus heterophylla | .41 |
| Chamæcyparis lawsoniana | .46 | Juglans cinerea | .41 |
| Picea nigra | .46 | Tilia pubescens | .41 |
| Abies nobilis | .46 | Picea alba | .41 |
| Taxodium distichum | .45 | Populus tremuloides | .40 |
| Æsculus glabra | .45 | Libocedrus decurrens | .40 |
| Tilia americana | .45 | Asimina triloba | .40 |
| Castanea dentata | .45 | Alnus oblongifolia | .40 |
| Catalpa catalpa | .45 | Pinus glabra | .39 |
| Salix nigra | .45 | Pinus monticola | .39 |
| Pinus flexilis | .44 | Pinus strobus | .38 |
| Acer negundo | .43 | Abies balsamea | .38 |
| Picea sitchensis | .43 | Populus trichocarpa | .38 |
| Æsculus octandra | .43 | Thuya plicata | .38 |
| Salix discolor | .43 | Pinus lambertiana | .37 |
| Tilia heterophylla | .43 | Abies concolor | .36 |
| Tsuga canadensis | .42 | Populus balsamifera | .36 |
| Liriodendron tulipifera | .42 | Abies grandis | .35 |
| Abies amabilis | .42 | Picea engelmanni | .34 |
| Sequoia sempervirens | .42 | Thuya occidentalis | .32 |
| Catalpa speciosa | .42 | Sequoia washingtoniana | .29 |
| Pinus albicaulis | .42 | Leitneria floridana | .21 |

*References*

ROTH, F.: Timber, Bul. 10, U. S. Div. Forestry, pp. 25–28.

SARGENT, C. S.: Forests of North America, Part 9, Tenth Census of the U. S., Washington, 1884, pp. 248–251.

GAYER, K.: Schlich's Manual of Forestry, Vol. V, 1908, pp. 50–65.

NÖRDLINGER, H.: Die Technischen Eigenschaften der Hölzer, Stuttgart, 1860, pp. 115–227.

## WATER CONTENT OF WOOD

Water occurs in living sapwood in three states, viz., (1) in the protoplasmic contents of the cells, (2) in the cell walls, and (3) as free water wholly or partially filling the lumina of cells, fibres, and vessels that have lost their contents. In heartwood water normally exists only in condition (2). In the fresh sapwood of *Pinus strobus*, which may be taken as fairly typical, water comprises about half of the total weight and is distributed approx-

imately as follows: in contents of living cells, 5 per cent; saturating cell walls, 35 per cent; free water, 60 per cent.

In a living tree the wood nearest the bark contains the most water. If no heartwood is present the decrease toward the pith is gradual; otherwise the change is quite abrupt at the sapwood limit. In *Pinus palustris*, for example, the weight of the fresh wood within an inch of the bark may be 50 per cent of water; that between one and two inches, only 35 per cent; that of the heartwood, only 20 per cent. The water content of any particular section of a tree depends upon the amount of sapwood, and is therefore greater for the upper than for the lower portions of the stem; greater for limbs than bole; greatest of all in the roots.

The water content of wood can readily be determined in the following manner: saw off a thin section of wood; weigh carefully on a delicate balance; dry in an oven at a temperature of 100° C. until a constant weight is obtained; reweigh. The difference between the fresh weight and the dry weight is the amount of moisture contained. Computed on a basis of the fresh weight,

$$\text{Per cent of moisture} = \frac{\text{fresh weight} - \text{dry weight}}{\text{fresh weight}} \times 100.$$

Thus if the weight of the original block of wood was twice the final weight, there was as much water as wood; in other words, one-half, or 50 per cent, of the original weight was water. The figures in the preceding paragraph are on this basis.

Computed on a basis of dry weight,

$$\text{Per cent of moisture} = \frac{\text{fresh weight} - \text{dry weight}}{\text{dry weight}} \times 100.$$

In the problem cited above the loss of moisture was 100 per cent of the dry weight. This method furnishes a constant basis for comparison, while the other varies with every change in moisture degree. Subsequent references to the per cent of moisture will refer to computation on the basis of dry weight.

It is impossible to remove absolutely all the water from wood without destroying the wood. Wood is considered thoroughly dried when it ceases to lose weight in a constant temperature of 100° C., though it still retains 2 to 3 per cent of moisture, and if exposed to higher temperature will continue to give up water.

*Seasoning*, which is essentially drying, adds appreciably to the strength, and, in slightly less proportion, to the stiffness of

wood. A piece of green spruce timber, for example, may become four times stronger when thoroughly dried.* This is an extreme case, however, and does not apply to large timbers where checking, which always occurs to some extent, may counterbalance partially or even entirely the gain in strength due to drying.

In small forms of hardwood material, as implement and carriage stock, and in coniferous timber in some forms, as cross-arms for telegraph poles, thorough and uniform reduction of the moisture content produces a large increase in strength. In fact a comparatively weak wood may, when perfectly dry, be much stronger than a strong wood in a green condition. Consequently tests to determine the mechanical properties of wood must, to be comparable, take into consideration the moisture content of the specimens. By means of a great many tests the relation of the moisture degree to the mechanical properties can be approximated and coefficients or correction factors determined by which the strength value at any given water content can be reduced to a standard (usually 12 per cent) or other desired moisture degree.†

Loss of water from cell lumina alone does not affect the mechanical properties of wood. It is only when the cell walls begin to give up their water that increase in strength, stiffness, hardness, and resilience occur. Conversely, the absorption of water weakens wood only to the point where the cell walls become completely saturated. This critical point has been termed by Tiemann (*loc. cit.*) the *fibre-saturation point*. It varies with different treatments of the wood and under different conditions. The water content at this point is greater in wood previously dried and especially in wood which has been subjected to high temperature than it is in green wood. The amount of moisture at the fibre-saturation point in green wood of various species has been found by Tiemann (*loc. cit.*) to be between 20 and 30 (average about 27) per cent.

The water content of wood materially affects durability. Since decay is produced by fungi, and to a less extent by bacteria, both of which require considerable water for their development,

* In comparing the strength and stiffness of wood in green and dry conditions, the fact should be borne in mind that, owing to shrinkage, dry wood is more compact and contains a greater amount of wood substance per unit of volume than green wood.

† Such tables have been prepared for several of the commercial woods of the United States. (See Bul. 70 and Cir. 108, U. S. Forest Service.)

all that is necessary to render even the most perishable wood indefinitely immune from decay is to keep it dry. Wood containing not more than 10 per cent of moisture will not decay.

Rate of seasoning differs with the kind of wood and with its shape. A thin piece dries more rapidly than a thicker one; sapwood more rapidly than heartwood; a light, open wood more readily than one that is dense and heavy. Large beams or logs are exceedingly slow in drying, requiring from two to several years' seasoning in the open air before reaching an air-dry condition in the interior. Ties require from three months to a year to season, depending on the kind of timber and the climate. Much depends upon the method of piling, since boards in open piles often dry twice as fast as those in solid piles.

As a result of numerous experiments by the U. S. Forest Service upon large beams of *Pinus palustris* and *P. tæda,* the following conclusions were reached (Bul. 70, p. 123):

"(1) The drying-out process takes place almost wholly through the faces of the beam and not longitudinally, except near the ends.

"(2) The ratio of evaporation through a surface is proportional to the rate of growth or density of the wood near the surface, being most rapid in the case of sapwood.

"(3) If the whole stick is made up of heartwood or the proportion of sapwood is uniform throughout, the longitudinal distribution of moisture is very regular. If the proportion of sapwood is not uniform, on the other hand, the portion containing the most sap is the most susceptible to moisture influences; *i.e.,* it will dry or will absorb moisture the most rapidly.

"The average of two cross-sections of longleaf pine sticks, 12 by 12 inches and 8 by 16 inches and 16 feet long, which were air-dried for two years, showed an average moisture content in the outer portion, cut halfway from surface to centre, of 17.7 per cent, while the inner part contained 25.7 per cent.

"From this it is quite evident that where timber of structural sizes is used, the strength ordinarily reckoned upon should not be greater than that of the green condition."

*References*

ROTH, F.: Timber, Bul. 10, U. S. Div. Forestry, pp. 29–31.

TIEMANN, H. D.: The Effect of Moisture upon the Strength and Stiffness of Wood, Bul. 70, U. S. Forest Service, 1906, p. 144.

TIEMANN, H. D.: The Strength of Wood as Influenced by Moisture, Circular 108, U. S. Forest Service, 1907, p. 42.

JOHNSON, J. B.: Timber Physics, Part II, Bul. 8, U. S. Div. of Forestry, 1893, pp. 22–24.

### SHRINKAGE, WARPING, AND CHECKING

The volume of wood is maximum when the cell walls are saturated with water. When this condition exists the presence or absence of free water in the cell cavities and the intercellular spaces does not affect the volume. When the cell walls begin to dry, they become thinner, but do not contract to an appreciable extent longitudinally. A dry wood cell is therefore of practically the same length as it was in a green or saturated condition, but is smaller in cross section, has thinner walls and a larger lumen. According to Nägeli's hypothesis, the cell wall is composed of aggregations in crystalline form of minute parts or *micellæ*. These *micellæ* are separated by films of water which become thinner as the wall dries and thicker as it swells. This shrinkage is roughly proportional to the thickness of the walls, and in consequence the denser woods or the denser portions of a wood shrink more than those less dense.

Inasmuch as wood is not a homogeneous substance, but an intricate structure composed of cells exhibiting from moderate to extreme variation in shape, size, thickness of walls, and more especially in arrangement, it follows that shrinkage cannot be uniform throughout any specimen. Late wood, being denser, shrinks more than early wood. The ray cells, with their longest diameters for the most part at right angles to the direction of the other elements, oppose radial shrinkage and tend to produce longitudinal shrinkage of wood. Only in the tangential direction are these otherwise opposing forces parallel. For this reason as well as the fact that the denser bands of late wood are tangentially continuous, while radially they are separated by alternate zones of less dense early wood, wood usually shrinks more than twice as much tangentially as it does radially. In all cases, however, shrinkage parallel to the vertical axis is very slight, one-tenth to one-third of one per cent, and is maximum in woods with curly or wavy grain or with large or very abundant rays.

The following table gives the results of a series of shrinkage

tests made by Mr. Hugh P. Baker at the Yale Forest School. The figures given represent the average shrinkage resulting from reducing green wood to a kiln-dry condition and are computed on the basis of the original measurements.

TABLE IV

SHRINKAGE OF WOOD ALONG DIFFERENT DIMENSIONS

| SPECIES. | Length % | Radius % | Diameter % | Circumference % | Area of cross section % | Volume % |
|---|---|---|---|---|---|---|
| Juniperus virginiana..... | 0.32 | 2.7 | 2.5 | 5.6 | 6.9 | 5.9 |
| Castanea dentata........ | .25 | 3.0 | 3.2 | 4.9 | 11.2 | .... |
| Quercus rubra........... | .24 | 3.7 | 3.5 | 8.2 | 10.4 | .... |
| Hicoria alba............ | .04 | 7.4 | 7.5 | 9.2 | 19.4 | 19.8 |
| Juglans cinerea.......... | .36 | 2.9 | 3.1 | 6.9 | 7.3 | 7.6 |
| Liriodendron tulipifera... | .15 | 4.3 | 4.8 | 9.3 | 12.6 | 13.7 |
| Nyssa sylvatica......... | .10 | 6.1 | 6.2 | 11.5 | 17.1 | 18.0 |

Irregularities in shrinkage tend to cause wood to become distorted or *warped*. In woods with straight grain and uniform texture the tendency to warp is minimum unless the distribution of the moisture content is very unequal. Thus the upper surface of a green board exposed to the hot rays of the sun will dry much more rapidly, and therefore becomes shorter than the lower side, causing the board to curl up at the ends. Woods with interlaced fibres or with cross or spiral grain (*e.g.*, *Nyssa*, *Liquidambar*, *Eucalyptus*) always shrink unequally, and consequently require careful handling in drying to prevent serious deformation. Warping due to unequal distribution of moisture may subsequently be overcome by thorough drying, but the deformation resulting from great irregularity of structure is usually permanent.

In Fig. 15 is shown in somewhat exaggerated manner the deformation caused by the greater tangential shrinkage. The flat side of a log cut through the middle becomes convex (*B*). Boards cut from half of a log assume the form shown in (*C*), while a plank from the middle of a log becomes convex on both sides. This explains most of the difference in shrinkage of timbers and boards of different sizes, shapes, and manner of sawing (*i.e.*, whether plain or quarter-sawed).

When the strains due to unequal shrinkage can no longer

be accommodated by the plasticity of the wood substance, cracks or checks are formed. These are most common along the rays, since there the strains are greatest and most complex. However, when the strength of the rays is greater than the cohesive force of the cementing substance uniting the two layers of the primary cell wall, radial fracture passes through the median plane of the primary wall of the wood cells instead of along the ray.

Variation in moisture content due to irregular drying results in checks, most of which are temporary, and as equilibrium becomes again established gradually close and become imperceptible. The more rapidly wood is dried, the greater is the tendency to check, for even if evaporation could be controlled so as to proceed uniformly throughout the specimen, the cells would not be given sufficient time to adjust themselves to the

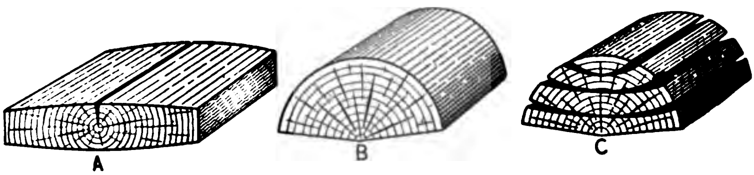


FIG. 15.

FIG. 15.—Effects of shrinkage. *A*, plank cut from middle of log (boxed heart), showing double-convex surfaces and large season check through upper half. *B*, log cut in half, showing the flat surface becoming convex and the appearance of three large season checks. *C*, half of a log cut into boards showing warping.

changed conditions. The presence of checks in wood, no matter how imperceptible, always impairs the strength of the material.

If the outer portion of a piece of wood, especially hard wood, dries much more rapidly than the inner, a hard shell is formed on the outside, while the interior retains most of its original moisture. This condition is known as *case-hardening*. This dry shell resists the transpiration of the moisture from the interior and retards drying, besides increasing the strains on the fibres. When the interior finally dries, the internal strains frequently become so great that large checks open up, producing a *honeycombed* condition.

Checks which result from greater shrinkage along the tangent than along the radius are permanent and increase in size as drying progresses (Figs. 1; 15 *B*). They cause serious difficulty in seasoning large timbers and especially material in the round, such as

logs, poles, and posts. If seasoned too rapidly hardwood timbers may split entirely open so as completely to destroy their value. In handling such material it is a common practice to forestall such checking by driving in *S*-shaped metal wedges across the incipient cracks. Such damage can also be reduced by more careful piling and handling of the material.

*References*

ROTH, F.: Timber, Bul. 10, U. S. Div. Forestry, pp. 32–37.

BOULGER, G. S.: Wood, pp. 80–88.

VON SCHRENCK, H.: Seasoning of Timber, Bul. 41, U. S. Bu. of Forestry, 1903, p. 48.

TIEMANN, H. D.: Effect of Moisture on the Strength and Stiffness of Wood, Bul. 70, U. S. Forest Service, pp. 76–79; 116–118; 123.

BAKER, HUGH P.: A Study in the Shrinkage of Wood (unpublished thesis, Yale Forest School, 1904).

CARRENS, C.: Zur Kenntniss der innern Structur der vegetabilischen Zellmembranen, Jahrb. für wissensch. Botanik, Vol. XXIII, 1892, pp. 567–636.

NÄGELI, K.: Ueber den innern Bau der Vegetabilischen Zellenmembranen, Sitzb. d. Akad. Wiss., München, 1864, Pt. 1, 282–326; Pt. 2, 114–170.

## HYGROSCOPICITY

Wood substance has the property of absorbing moisture from the atmosphere. When artificially dried wood is exposed to the open air it will increase in weight, due to the addition of hygroscopic water. Although the amount of water thus attracted is always greater than in the surrounding air, it does not remain constant, but varies with the humidity, and is equal to 8 to 16 (average 12) per cent of the dry weight of the wood. These variations are accompanied by proportionate changes in volume, that is, the wood alternately shrinks and swells, or "works." Hygroscopicity can be reduced, but not entirely eliminated, by subjecting wood to boiling, steaming, prolonged soaking, or exposure to high temperature.

This property of wood is a serious hindrance to its use in certain positions where exact fitting is permanently desired. Drawers and doors "stick" in damp weather, and become loose in dry weather, or when artificially heated and dried for con-

siderable time. Furniture, wainscoting, interior finish, and cabinet work may be badly damaged by prolonged drying, which opens up joints, loosens tenons, and causes veneers to separate from their backing. This property may be largely overcome by soaking wood in oil or coating the surface with paint, oil, or varnish, which excludes most of the air and moisture and keeps the condition of the wood uniform. Light, porous woods "work" less than dense woods. On account of their greater porosity and lightness, slowly grown ring-porous woods (Fig. 13) shrink and swell less than specimens of the same species more rapidly grown (Fig. 14).

The presence of natural oils, gums, and pigments such as are commonly found in the heartwood of many species usually reduces the hygroscopicity of woods.

*References*

Roth, F.: Timber, Bul. 10, U. S. Div. For., pp. 30–31.

Exner, W. F.: Lorey's Handbuch der Forstwissenschaft, Vol. II, 1903, pp. 128–129.

Gayer, K.: Schlich's Manual of Forestry, Vol. V (1908), pp. 66–75.

## PENETRABILITY

In all green wood the cells are separated from each other by a thin membrane, the primary cell wall. The only important exceptions are the vessels between whose segments there is free communication vertically. Vessels, however, like other cells, are separated from each other and from other elements by the primary wall. This wall ordinarily persists intact unless ruptured by parenchymatous outgrowths—tyloses. It is permeable by water and certain dilute solutions which filter through slowly, but is impervious to oils and resins. Gases can enter into living cells only by going into solution, and in that condition diosmosing through the cell wall.

These facts have an important bearing on the process of impregnating wood with preservatives to prevent decay. It is not difficult to force gases or fluids through open vessels of green wood, but it is impossible to do so if they are plugged with tyloses. For example, it is very easy to blow through the vessels of green wood of most red or black oaks, even in pieces of considerable length. In green wood of the white oaks, on the other hand,

it is impossible to force any air through the vessels, even for short lengths and with very high pressure, since in this case they are blocked with tyloses. Even in the red or black oaks, however, air cannot be forced through the other elements of green wood.

When wood becomes dry its penetrability by both gases and liquids is increased to a remarkable extent. The same specimen of white oak which, while green, effectually withstood an air pressure of 150 pounds per square inch will, when dry, allow the passage of air, not only through the vessels, but also the other elements, under a pressure of 5 pounds per square inch or less. Similar effects are produced by drying any wood beyond its fibre-saturation point. This fact emphasizes the great importance of seasoning wood before attempting to impregnate it with preservatives.

According to Tiemann (*loc. cit.*), the explanation of this is that the drying of the cell walls causes minute checks or slits to occur in the primary walls. The dryer the wood becomes the larger the slits and the more permeable the wood. These slits do not entirely close when the wood is resoaked, so that wood once dried cannot be restored to its original condition.

Steaming is said to produce similar results, though the slits apparently are not as wide as when wood is air-dried. It is probable, however, that the maximum amount of slitting would result from thoroughly drying wood that had been previously steamed. Boiling green wood in oil results in more or less seasoning of the outer portions, thus allowing some penetration by the oil.

Dry woods, however, differ greatly in penetrability. Light, porous woods as a rule are much easier to impregnate than dense, compact ones. Heartwood of any species offers more resistance than the sapwood, due probably to the presence in the walls of gums, resins, and other infiltrations. Tyloses, which always reduce penetrability, are mostly absent from the outer portion of sapwood even when very abundant in the heartwood of the same tree. In the wood of Gymnosperms it appears that the wood-parenchyma cells are more penetrable than the tracheids. Open resin ducts permit the entrance of fluids into the body of the wood, behaving in a manner similar to the vessels of Dicotyledons.

The whole question of the penetrability of wood is extremely important in view of the increasing interest in timber preservation, and comparatively little is definitely known regarding it. Experiments by the United States Forest Service are now in

progress which should add materially to the present knowledge of the subject.

*Reference*

TIEMANN, HARRY D.: The Physical Structure of Wood in Relation to Its Penetrability by Preservative Fluids, Bul. 120, Am. Ry. Eng. and Maintenance of Way Ass'n, Jan. 1910.

### CONDUCTIVITY

Dry wood is a very poor conductor of heat, as is well illustrated in its use for matches and as handles for utensils and tools subjected to various temperatures. Increase in density or in moisture content increases the conductivity of wood. Woods are most conductive in direction parallel to the grain and least so in radial direction, the ratio in some instances being as high as 2 to 1. The difference between radial and tangential directions in this regard is slight, and is probably due to the fact that in a tangential direction the bands of the denser and therefore more conductive late wood are continuous, while radially they are interrupted by alternate bands of the less dense early wood.

Wood in a dry condition is a non-conductor of electricity. Increase of water content reduces its value as an insulator. Light, porous woods are more resistant to the passage of electric currents than are dense woods; highly resinous woods, more than woods without resin, since resin and oil are poor conductors of electricity.

Wood is a good conductor of sound, particularly in a longitudinal direction. The denser, the more uniform, and the dryer the wood the greater is its ability to transmit sound. Unsoundness and decay materially reduce this property.

*References*

GAYER, KARL: Schlich's Manual of Forestry, Vol. V, 1908, pp. 78–79.

EXNER, W. F.: Lorey's Handbuch der Forstwissenschaft, Vol. II, p. 117.

MATHEY, ALPHONSE: Traité d'Exploitation Commerciale des Bois, Vol. I, Paris, 1906, pp. 63–65.

NÖRDLINGER, H.: Die Technischen Eigenschaften der Hölzer, pp. 56–114.

### RESONANCE

"If a log or scantling is struck with the ax or hammer, a sound is emitted which varies in pitch and character with the

shape and size of the stick, and also with the kind and condition of wood. Not only can sound be produced by a direct blow, but a thin board may be set vibrating and be made to give a tone by merely producing a suitable tone in its vicinity. The vibrations of the air, caused by the motion of the strings of the piano, communicate themselves to the board, which vibrates in the same intervals as the string and reënforces the note. The note which a given piece of wood may emit varies in pitch directly with the elasticity, and indirectly with the weight, of the wood. The ability of a properly shaped sounding-board to respond freely to all the notes within the range of an instrument, as well as to reflect the character of the notes thus emitted (*i.e.*, whether melodious or not), depends, first on the structure of the wood, and next on the uniformity of the same throughout the board. In the manufacture of musical instruments all wood containing defects, knots, cross grain, resinous tracts, alternations of wide and narrow rings, and all wood in which summer and spring wood are strongly contrasted in structure and variable in their proportions are rejected, and only radial sections (quarter-sawed, or split) of wood of uniform structure and growth are used.

"The irregularity in structure, due to the presence of relatively large pores and pith rays, excludes almost all our broad-leaved woods from such use, while the number of eligible woods among conifers is limited by the necessity of combining sufficient strength with uniformity in structure, absence of too pronounced bands of summer wood, and relative freedom from resin.

"Spruce is the favored resonance wood; it is used for sounding-boards both in pianos and violins, while for the resistant back and sides of the latter, the highly elastic hard maple is used. Preferably resonance wood is not bent to assume the final form; the belly of a violin is shaped from a thicker piece, so that every fiber is in the original in as nearly an unstrained condition as possible, and therefore free to vibrate. All wood for musical instruments is, of course, well seasoned, the final drying in kiln or warm room being preceded by careful seasoning at ordinary temperatures often for as many as seven years or more. The improvement of violins, not by age, but by long usage, is probably due, not only to the adjustment of the numerous component parts to each other, but also to a change in the wood itself; years of vibrating enabling any given part to vibrate much more readily." *

* Roth, F., Timber, Bul. 10, U. S. Div. For., pp. 24–25.

## COLOR

When wood is first formed it is almost, if not entirely, colorless, as may be observed in the outermost growth rings in any species. After a year or two it usually becomes yellowish, and still later when changed into heartwood a decided deepening of color results. Exceptions to this rule are rather numerous, for example, *Picea, Tsuga, Abies, Salix, Alnus, Betula, Ilex,* and *Æsculus* exhibit little or no contrast in color between heartwood and sapwood. In all species the sapwood has a very limited range of color and shade, but the heartwood exhibits great variation, from the chalky white of *Ilex opaca* to the ebony black of old *Diospyros virginiana,* with practically all intermediate colors, shades, and tints. In many woods the demarcation in color between heartwood and sapwood is very sharp and distinct, while in others the transition is gradual. In some instances (*e.g., Sequoia, Ilex, Catalpa, Cladrastis lutea*) the color is uniform, while in others (*e.g., Liriodendron, Liquidambar, Swietenia*) it is variable not only in different specimens, but in different portions of the same piece. The golden yellow of *Toxylon* shows narrow streaks of red; *Liquidambar* shows black streaks that usually give the finished lumber a handsome watered effect; *Liriodendron* varies from deep iridescent blue to yellowish brown; *Robinia* varies from light straw-colored to deep golden yellow like *Toxylon; Taxodium* is sometimes nearly black, often yellowish, reddish, brown, or mottled. The deep-colored wood of *Juniperus* frequently exhibits streaks of white sapwood, the intermingling resulting from the fluted periphery of the stem.

It is generally true that depth of color of woods is a criterion of durability. Thus the dark heartwood of *Juniperus, Sequoia, Prosopis, Toxylon, Robinia,* and *Morus* is very resistant to decay, while that of *Salix, Populus, Tilia, Æsculus, Acer, Fraxinus,* and *Nyssa* is perishable. The deeper color of the heartwood is due to the infiltration or deposition in the cell walls and lumina of gums, resins, pigments, tannin, and other substances. To these is ascribed the greater durability of wood, since sapwood is invariably not durable under exposure. In some instances, however (*e.g., Chamæcyparis, Taxodium, Catalpa, Sassafras*), the infiltrated substances tend to prevent decay without greatly deepening the color of the heartwood.

Color adds greatly to the value of wood for interior finish, cabinet work, marquetry, and parquetry. It is a very common practice to stain wood artificially. Light-colored and therefore less valuable wood of mahogany, such as commonly grows in the United States and Mexico, is often darkened; *Ilex opaca* is readily stained black to resemble ebony; *Betula lenta*, when properly stained, is a good imitation of mahogany; in fact, by the application of stains and finishes the variations in color and shade that can be produced in woods is practically unlimited. It is also possible by the introduction of certain chemicals to color the sapwood of a living tree.

For some uses of wood lack of color is prized. This is especially true of pulpwood, since coloring matter, if present, must be bleached out. Color is also undesirable in certain grades of flooring. In handles and spokes dark color is considered a defect, since it indicates heartwood, which is usually (but erroneously) thought to be weaker than the colorless sapwood.

All woods darken upon exposure to the atmosphere, probably due to the oxidation of the coloring matters. The rich golden yellow of *Toxylon* and *Morus* becomes a dark or russet brown; the sapwood of *Alnus oregona* turns reddish brown; *Pinus monticola* and *P. strobus* often become vinous red, especially near the end of an exposed piece of wood. On this account the natural color of a wood can only be seen on fresh-cut sections. Prolonged immersion in water causes wood to darken—some turning gray, others almost black.

Some woods (*e.g.*, *Cladrastis lutea, Prosopis, Sequoia, Juglans*) impart color to water in which they are soaked. The color of many others can be removed by treatment with NaOH or other chemicals, but it is often necessary to reduce the wood to pulp before it can be bleached. Many tropical woods (*e.g.*, *Clorophora tinctoria, Hæmatoxylon campechianum, Cæsalpina, Pterocarpus*) contain coloring principles of value in the arts for dyeing, though they have been largely superseded by aniline dyes. Of indigenous woods, *Toxylon pomiferum* and several species of *Xanthoxylum* are sometimes employed for this purpose, usually as adulterants of old fustic (*Clorophora*).

Color is often of great assistance for diagnostic purposes, though the range of variation and difficulty of description must always be taken into consideration. Unless otherwise stated, the colors mentioned in the key refer always to the fresh cross section

of a piece of dry wood. The character of the demarcation in color between heartwood and sapwood, whether sharp or gradual, is often an important feature, though usually not exhibited on very small specimens. The character and amount of coloring matter extracted by treatment with NaOH is sometimes made use of in identification.

Abnormal discoloration of wood usually denotes disease. The black check in *Tsuga heterophylla* is the result of insect attacks. The reddish-brown streaks so common in *Hicoria* are mostly the result of injury by birds. The bluing of the sapwood of many soft woods is due to the attacks of fungi. Many fungi can be determined specifically by the characteristic color they impart to wood.

*References*

ROTH, F.: Timber, Bul. 10, U. S. Div. For., p. 24.

GAYER, K.: Schlich's Manual of Forestry, Vol. V (1908), pp. 43–46.

HANAUSEK, T. F.: The Microscopy of Technical Products.

MELL, C. D.: Fustic Wood, Cir. 184, U. S. Forest Service.

EXNER, W. F.: Lorey's Handbuch der Forstwissenschaft, Vol. II, pp. 105–111.

NÖRDLINGER, H.: Die Technischen Eigenschaften der Hölzer, pp. 46–51.

## GLOSS OR LUSTRE

Gloss or lustre of wood refers to the manner in which light is reflected by the wood elements. The fibres of the bast are more lustrous than the wood fibres. The fibre of flax is highly lustrous, while that of cotton is dull. Similar variation occurs in the elements of different woods. For example, the woods of *Fagara*, *Rhus*, and *Toxylon* are highly lustrous; those of *Acer*, *Betula*, and *Robinia* less so; while those of *Juglans nigra*, *Sequoia*, *Fagus*, and *Platanus* are dull. The wood of *Picea* possesses a pearly lustre; that of *Guaiacum* and *Taxodium* is rather greasy or waxy. In some cases the lustre varies in different parts of the wood or on different planes. The late wood of *Juniperus virginiana* exhibits a frosted lustre on tangential surface. The rays on quarter-sawed wood of several species, particularly the oaks, are so lustrous in contrast to the other elements as to give rise to the term "silver grain," while the rays themselves are called "mirrors." Woods with high natural lustre are usually capable of taking a high polish. Lustre is a sign of soundness

in wood, for incipient decay causes wood to become dull and "dead." Sound wood in thin sections is translucent and exhibits double refraction. The presence of rosin in wood increases its translucency.

*References*

GAYER, K.: Schlich's Manual of Forestry, Vol. V (1908), pp. 47, 79.
EXNER, W. F.: Lorey's Handbuch der Forstwissenschaft, pp. 111–112.
NÖRDLINGER, H.: Die Technischen Eigenschaften der Hölzer, pp. 46–51.

### SCENT OR ODOR

Every wood when fresh possesses in some degree a characteristic scent, though in a great many cases it is so weak or fleeting that it escapes notice. Odor depends upon chemical compounds (*e.g.*, ethereal oils and tannin) which form no part of the wood itself. Ordinarily it is more pronounced in heartwood than in sapwood. It is also greater in wood in a green condition than when seasoned, more evident on moist surfaces than on dry. Upon prolonged exposure to air, or when submerged in water, wood gradually loses its scent. In some cases the loss is complete throughout; in others only the outer portions are affected. Woods deriving their odors from the presence of ethereal oils, as is the case in many cedars, apparently may be kept indefinitely and still emit their characteristic odors when a fresh surface is exposed.

Upon exposure to the air for a short time some green woods (*e.g.*, *Quercus*) acquire a disagreeable, soured odor, probably due to the decomposition of certain organic compounds. Woods in process of decay emit various odors, sometimes very disagreeable (*e.g.*, *Populus*), sometimes not unpleasant (*e.g.*, *Quercus*), but always different from the natural scent characteristic of the sound wood.

The fumes of burning wood are occasionally characteristic. Resinous woods, as *Pinus*, give off an odor of tar. The woods of *Juniperus virginiana* and *Chamæcyparis lawsoniana* burn with a pungent, spicy scent, giving the latter a special value for match-sticks. The woods of *Cercidium* and *Parkinsonia* give off very penetrating, disagreeable fumes when burned, reducing materially their desirability for fuel.

The scent of certain woods renders them commercially valuable. Cigars are believed to be considerably improved by being kept in

cedar boxes. The scent of cedar (*Juniperus virginiana, Chamæcyparis lawsoniana,* and *C. nootkatensis*) is apparently disagreeable to moths and other insects, making the wood desirable for cabinets, wardrobes, chests, and drawers where furs and woolen clothes are kept. Cedar shavings are also employed for the same purpose. Loss of scent from the exposed surface of the wood soon seriously impairs the efficiency of the wood for this purpose. For some purposes, especially as receptacles for wines, liquors, drinking-water, and oils, meats, fish, butter, and other foodstuffs, highly-scented wood is undesirable since it is apt to taint the contents.

While scent is often a very valuable aid to the identification of wood, its utility is lessened by the difficulty and often impossibility of describing an odor so that one unfamiliar with it would be able to recognize it. Such descriptions are necessarily limited to comparisons with well-known scents which are usually inadequate. The scent of the wood of *Pinus* is resinous or like turpentine; that of *Juniperus* and *Chamæcyparis thyoides* aromatic, like cedar oil; that of *Chamæcyparis nootkatensis, C. lawsoniana,* and *Libocedrus decurrens* spicy-resinous; that of dark-colored, waxy specimens of *Taxodium,* like rancid butter; that of *Catalpa* somewhat like kerosene; that of *Viburnum lentago* and *V. prunifolium* very disagreeable and pungent.

The following genera and species usually can be recognized by their odor alone: *Juniperus, Chamæcyparis thyoides, C. lawsoniana, Libocedrus, Thuya, Tsuga canadensis, Sassafras, Viburnum,* and *Catalpa.* With a keen sense of smell others may be recognized; for example, *Pinus, Taxodium, Quercus, Castanea, Ulmus,* and *Betula.* Prominent among exotic species characterized by pronounced scents are the camphor trees (*Cinnamomum camphora, Dryobalanus camphora, Camphora glanduliferum*), Indian sandalwood (*Santalum album*), and violet-wood (*Acacia homophylla*).

*References*

Gayer, K.: Schlich's Manual of Forestry, Vol. V (1908), pp. 47–48.
Roth, F.: Timber, Bul. 10, U. S. Div. For., p. 24.
Krais, Paul: Gewerbliche Materialkunde, Vol. I, Die Hölzer, p. 652.
Exner, W. F.: Lorey's Handbuch der Forstwissenschaft, Vol. II, pp. 116–117.
Nördlinger, H.: Die Technischen Eigenschaften der Hölzer, pp. 51–53.

### TASTE

Wood substance itself, being insoluble in water or weak alkaline solutions, is necessarily tasteless. The characteristic taste of certain woods is due then to soluble substances deposited in the cell lumina or infiltrated into the cell walls. In any wood the most pronounced flavor is obtained from the sapwood; it is also more pronounced in green material than in dry. This is probably due to the fact that the substances giving wood its flavor were in solution or soluble form in the living sapwood. When submerged in water they may be leached out, and when exposed to air, oxidized.

Taste is occasionally helpful in identifying woods, though, like odor, it cannot be described with accuracy. The wood of *Libocedrus decurrens* has a very spicy flavor; that of *Pinus palustris* terebinthic; that of *Chamæcyparis lawsoniana* spicy-resinous; that of *Sassafras* rather spicy. The wood of *Castanea* has no special flavor, but on account of the tannin in it, has an astringent effect on the mouth.

## LIST OF GENERAL CLASSIFICATIONS OF WOODS

BOULGER, G. S.: Wood (2d edition, London, 1908), pp. 41–54.

BRANDIS, D.: Forest Flora of North-West and Central India, Preface, p. xxx.
See also Gamble's Manual of Indian Timbers, Introduction, p. xviii.

DEBARY, A.: Comparative Anatomy of the Vegetative Organs of the Phanerogams and Ferns (English edition, Oxford, 1884), pp. 495–496. (Classification condensed from Sanio.)

FOXWORTHY, FRED W.: Key to Philippine Commercial Woods, The Philippine Journal of Science, C. Botany, Vol. II, No. 5, Oct. 1907, pp. 364–369.

HANAUSEK, T. F.: The Microscopy of Technical Products (English edition, New York, 1907), pp. 211–243.

HARTIG, R.: Die Unterscheidungsmarkmale der wichtigeren in Deutschland wachsenden Hölzer, Munich, 1883.
See Gamble's Manual of Indian Timbers, Intr., p. xvii.

HARTIG, TH.: Anatomie und Physiologie der Holzpflanzen (Berlin, 1878), pp. 177–179.

KIENITZ, M.: Schlüssel zum Bestimmen der wichtigsten in Deutschland wachsenden Hölzer, Munich, 1879.

KRAIS, PAUL: Gewerbliche Materialkunde, Vol. I, Die Hölzer (Stuttgart, 1910), pp. 657–731.

MATHIEU, M.: Flore Forestière (4th edition).
For translation of classification, see Gamble's Manual of Indian Timbers, Intr., p. xvii.

————: Table pour Determiner les Coupes Transversales des Bois Indigènes les plus Utiles à l'Aide de la loupe ou de la Simple Vue. See Beauverie's Le Bois (Paris, 1905), Vol. II, p. 64.

MÜLLER, N. J. C.: Atlas der Holzstructur (Münden, 1888), pp. 54–55; 90–91.

PENHALLOW, D. P.: North American Gymnosperms (Boston, 1907), Part II.

ROTH, FILIBERT: Timber, Bul. 10, U. S. Div. of Forestry, Washington, D. C., 1895.
See also Johnson's Materials of Construction (New York, 1902), Chap. XIII.

SANIO, CARL: Vergleichende Untersuchungen über des Holzkörpers, Bot. Zeit., Vol. XXI, No. 51, 1863, pp. 401–408.

SCHACHT, H.: Der Baum (Berlin, 1853), pp. 377–396.

SHROEDER, J.: Schlüssel zur Bestimmung des Coniferen-Holzes nach den histologischen Merkmalen. See Tursky's Tabellen zur Bestimmung des Holzes und der Zweige in blattlosem Zustande der wichtigsten Baum- und Straucharten, Nachrichten der Petrowski'schen Agricultur- und Forstakademie Moskau, Jahrgang VII, 1883, No. 1, pp. 35–74.

STRZELECKI, H.: Klucz do rozpoznawania drewna wazniejszych drzew i drzewów leśnych i ogrodowych (Key for determining the wood of the most important trees and shrubs), Kosmos, Organ d. poln. Naturforscher-Ver. Copernicus, Vols. VII–VIII, 1881, pp. 385–387.

WARD, MARSHALL: Timber and Some of its Diseases (London, 1889), pp. 54–59.
See also Gamble's Manual of Indian Timbers (London, 1902), Intr., p. xviii.

WIESNER, JULIUS: Die Rohstoffe des Pflanzen Reiches, Vol. II (Leipzig, 1903), pp. 145–146.

## PUBLICATIONS DEALING WITH THE CHARACTERISTICS OF WOODS

ABROMEIT, JOHANNES: Ueber die Anatomie des Eichenholzes. Berlin, G. Bernstein, 1884.

AHERN, GEORGE P.: The Uses of Philippine Woods, Bul. 11, Philippine Bu. Forestry, Manila, P. I. 1911.

BALFOUR, EDWARD: The Timber Trees and Fancy Woods, as also the Forests of India, and Eastern and Southern Asia (3d ed.). Madras, Higgenbotham & Co., 1870.

BASTIN, EDSON S., AND TRIMBLE, HENRY: A Contribution to the Knowledge of the North American Coniferæ. Reprint, American Journal of Pharmacy, Vols. LXVIII–LXIX, 1896–7.

BATERDEN, J. R.: Timber. New York, D. van Nostrand & Co., 1908.

BEAUVERIE, J.: Le Bois. Vol. I–II. Paris, Gauthier-Villars, 1905.

————: Le Bois Industriels. Paris, O. Doin et fils, 1910.

BOULGER, G. S.: Wood: a Manual of the Natural Histories and Industrial Applications of the Timbers of Commerce (2d ed.). London, Edward Arnold, 1908.

BRANDIS, SIR DIETRICH: Indian Trees. London, A. Constable & Co., 1906.

BRITTON, N. L.: North American Trees. New York, Henry Holt & Co., 1906.

BRUAND, M., ET AL: Notices sur le Débit et les Emplois du Chataignier, des Érables, du Frêne, des Ormes, de L'Aune, du Bouleau, du Saule, du Tilleul, du Tremble, du Charme, de L'Aliser, du Cerisier-Merisier, du Cornouiller, du Coudrier, du Micocoulier, du Poirer, du Pommier, du Robinier, du Sorbier-Cormier. Paris, Imprimerie Nationale, 1878.

BURGERSTEIN, A.: Anatomische Untersuchungen samoanische Hölzer, K. Rechinger, Botanische und Zoologische Ergebnisse einer wissenschaftlichen Forschungsreise nach den Samoainseln, dem Neuguinea-Archipel und den Salomoninseln. IV. Teil, Denkschriften d. Mathemat. naturwissensch. Klasse kais. Ak. Wiss. LXXXIV, Wien, 1908.

CHARPENTIER, PAUL: Timber: a Comprehensive Study of Wood in All its Aspects (trans. from the French by Joseph Kennell). London, Scott, Greenwood & Co., 1902.

Croizette-Desnoyers, M.: Notice sur le Debit et les Emplois des Principales Espèces de Pins. Paris, Imprimerie Nationale, 1878.

Dupont, A. E., and La Grye, B. de: Les Bois: Indigènes et Étrangers. Paris, J. Rothschild, 1875.

Engler, A.: Einige Nutzhölzer Kameruns, I, Olaceæ, Notizblatt d. königl. bot. Gärten und Museums zu Dohlem (Berlin), Appendix XXI, No. 1, Jan. 20, 1909.

Exner, William F.: Die Technischen Eigenschaften der Hölzer (Chap. VI of Lorey's Handbuch der Forstwissenschaft, Vol. II. Tübingen, H. Laupp, 1903).

Foxworthy, Fred W.: Philippine Woods, Phil. Journal of Sci., C. Botany, Vol. II, No. 5, Manila, P. I., October, 1907.

Gamble, J. S.: Manual of Indian Timbers (rev. ed.). London, S. Low, Marston & Co., 1902.

Gayer, Karl: Forest Utilization (Vol. V of Schlich's Manual of Forestry; trans. from the German by W. R. Fisher; 2d ed.). London, Bradbury, Agnew & Co., 1908.

Hall, William L., and Maxwell, Hu.: Uses of Commercial Woods of the United States: I. Cedars, Cypresses, and Sequoias; Bul. 95; II. Pines, Bul. 99. U. S. Forest Service, Washington, D. C., 1911.

Harms, H.: Einige Nutzhölzer Kameruns: II, Leguminosæ, Notizblatt d. königl. bot. Gärten u. Museums zu Dohlem bei Steglitz (Berlin). Appendix XXI, No. 2, July 15, 1911.

Hartig, Robert: Timbers and How to Know Them; translated from the 3d German edition by Dr. William Somerville. Edinburgh, D. Douglas, 1890.

Hartig, Theodor: Anatomie und Physiologie der Holzpflanzen. Berlin, Julius Springer, 1878.

Hay, R. D.: The Principal Timbers of New South Wales and Their Uses. Sydney, 1906.

Hesselbarth, Guido: Beiträge zur Vergleichenden Anatomie des Holzes. Leipzig, Druck der Rossberg'schen Buchdruckerei, 1879.

Hough, Franklin B.: The Elements of Forestry. Cincinnati, The Robert Clarke Co., 1898.

Hough, Romeyn B.: American Woods (Sections and Text). Vols. I–XII. Lowville, N. Y., the author, 1893–1911.

HOUGH, ROMEYN B.: Handbook of the Trees of the Northern States and Canada East of the Rocky Mountains. Lowville, N. Y., the author, 1907.

HUBERT, E.: Le Bois et le Liège, Paris, J. B. Baillière & Sons, 1902.

JACCARD, P.: Étude Anatomique de Bois comprimés, 48 pp., illus., plates. Zurich, Switzerland, F. Lohbauer, 1910.

JANSSONIUS, H. H.: Mikrographie des Holzes der auf Java vorkommenden Baumarten, Pub. Departments für Landwirtschaft in Buitenzorg. Leiden, E. J. Brill, Part I, 1906; Part II, 1908; Part III, 1911.

JEPSON, WILLIS L.: The Silva of California (Vol. II, Memoirs of the University of California). Berkeley, University Press, 1910.

KOTTMEIER, H., AND UHLMANN, F.: Das Holz. Leipzig, Quelle & Meyer, 1910.

KRAIS, PAUL: Gewerbliche Materialkunde: Die Hölzer. Stuttgart, Felix Krais, 1910.

LARIS, E.: Rohholzgewinnung und Gewerbseigenschaften des Holzes. Vienna and Leipsic, 1909, pp. 184.

LASLETT, THOMAS: Timber and Timber Trees, Native and Foreign (2d ed.; revised and enlarged by H. Marshall Ward). London and New York, Macmillan & Co., 1894.

MACKENZIE, D. F.: The Identification of Timber: with a Uniform Series of Photo-micrographs. Trans. Highland and Agr. Soc. of Scotland, Ser. 5, Vol. XII, 1900, pp. 183–224.

MCTURK, MICHAEL: Wood of British Guiana. Georgetown, Government report, 1902.

MANN, JAMES: Australian Timber: its Strength, Durability, and Identification. Melbourne, Walker, May & Co., 1900.

MARTIN-LAVIGNE, E.: Recherches sur les Bois de la Guyane. Leur identification à l'aide des caractères extérieurs et microscopiques. Trav. Lab. Mat. med. Ec. sup. Pharm., Paris, VI, 1910, pp. 1–181.

MATHEY, ALPHONSE: Traité d'Exploitation Commerciale des Bois. Vols. I–II. Paris, Lucien Laveur, 1908.

MELL, CLAYTON D., AND BRUSH, W. D.: Quebracho and Its Substitutes. Cir. 202, U. S. Forest Service, Washington, D. C., 1912.

MOELLER, JOSEPH: Beiträge zur vergleichenden Anatomie des Holzes. Wien, 1876.

————: Anatomie der Baumrinden. Vergleichende Studien. Berlin, Julius Springer, 1882.

————: Die Rohstoffe des Tischler- und Drechslergewerbes. Theil I: Das Holz. Cassel, Theodor Fischer, 1883.

MOHR, CHARLES, AND ROTH, FILIBERT: The Timber Pines of the Southern United States, together with a Discussion of the Structure of their Wood. Bul. 13 (rev. ed.), U. S. Div. Forestry, Washington, D. C., 1897.

MÜLLER, N. J. C.: Atlas der Holzstructur. Halle A. S., Wilhelm Knapp, 1888.

NÖRDLINGER, H.: Die Technischen Eigenschaften des Hölzer für Forst und Baubeamte. Technologen und Gewerbtreibende. Stuttgart, J. G. Cotta, 1860.

PENHALLOW, DAVID P.: A Manual of the North American Gymnosperms, exclusive of the Cycadales, but together with Certain Exotic Species. Boston, Ginn & Co., 1907.

PINCHOT, GIFFORD, AND ASHE, W. W.: Timber Trees and Forests of North Carolina. Bul. 6, N. C. Geol. Survey, Chapel Hill, N. C., 1897.

RATTINGER, K. K.: Die Nutzhölzer der Vereinigten Staaten, I, Die Nadelhölzer, Wiesbaden, Verlag Forstbüro, 1910.

RIZZI, P.: Technologia forestale ed Utilizzazione dei Boschi. Milan, F. Vallardi, Vol. I, 1897; Vol. II, 1898.

ROTH, FILIBERT: Timber: an Elementary Discussion of the Characteristics and Properties of Woods. Bul. No. 10, U. S. Div. of Forestry, Washington, D. C., 1895.

SARGENT, CHAS. S.: Report on the Forests of North America (exclusive of Mexico). Vol. IX, Tenth Census, Washington, D. C., 1884.

————: The Woods of the United States, with an Account of the Structure, Qualities and Uses (Jesup Collection). New York, D. Appleton & Co., 1885.

————: The Silva of North America: a Description of the Trees which Grow Naturally in North America, exclusive of Mexico. Vols. I–XIV. Boston and New York, Houghton Mifflin Co., 1891–1902.

SARGENT, CHAS. S.: Manual of the Trees of North America (exclusive of Mexico). Boston and New York, Houghton Mifflin Co., 1905.

SCHACHT, HERMANN: Der Baum. Studien über Bau und Leben der Höheren Gewächse. Berlin, G. M. F. Müller, 1853.

SCHROEDER, JULIUS: Das Holz der Coniferen. Dresden, 1872.

SKINNER, W.: Description, etc., of Indian and Burmese Timbers. 1862.

SNOW, C. H.: The Principal Species of Wood (2d ed.). New York, John Wiley & Sons, 1908.

SOLEREDER, HANS: Systematic Anatomy of the Dicotyledons. Vols. I–II (Eng. trans.). Oxford, Clarendon Press, 1908.

STEPHENSON, WILLIAM: The Trees of Commerce (rev. ed.). London, W. Ryder & Son, 1908.

STONE, HERBERT: The Timbers of Commerce and Their Identification. London, W. Ryder & Son, 1904.

SUDWORTH, GEORGE B.: Forest Trees of the Pacific Slope. U. S. Forest Service, Washington, D. C., 1908.

——— AND MELL, CLAYTON D.: The Identification of Important North American Oak Woods, based on a Study of the Secondary Wood. Bul. 102, U. S. Forest Service, Washington, D. C., 1911.

———: "Colombian Mahogany," Its Characteristics and Its Use as a Substitute for True Mahogany. Cir. 212, U. S. Forest Service, Washington, D. C., 1911.

———: Circassian Walnut and Its Substitutes. Cir. 210, U. S. Forest Service, Washington, D. C., 1912.

———: Identification of North American Walnut Woods. Bul. 120, U. S. Forest Service, Washington, D. C., (in press).

———: Distinguishing Characteristics of North American Gumwoods, based on the anatomy of the secondary wood. Bul. 103, U. S. Forest Service, Washington, D. C., 1911.

TROUP, R. S.: Indian Woods and Their Uses, Indian Forest Memoirs, Vol. I, No. 1. Imperial Forest Research Institute of India, 1909.

WARREN, W. H.: The Strength, Elasticity, and Other Properties of New South Wales Hardwood Timbers. N. S. W. Dept. of Forestry, Sydney, 1911.

WHITFORD, H. N.: The Forests of the Philippines. Part I, Forest Types and Products. Part II, The Principal Forest Trees. Bul. 10, Philippine Bu. of Forestry, Manila, P. I., 1911.

WIESNER, JULIUS: Die Rohstoffe des Pflanzen Reiches. Vol. II. Leipzig, Wilhelm Engelmann, 1903.

WILDA, HERMANN: Das Holz: Aufbau, Eigenschaften und Verwendung, Leipzig, G. J. Göschen, 1910.

## PUBLICATIONS DEALING WITH THE USES OF AMERICAN WOODS

BETTS, H. S.: Properties and Uses of the Southern Pines. Cir. 164, U. S. Forest Service, Washington, D. C., 1909, pp. 30.

CLINE, McGARVEY, AND KNAPP, J. B.: Properties and Uses of Douglas Fir. Bul. 38, U. S. Forest Service, Washington, D. C., 1911, pp. 75.

DODGE, CHARLES RICHARDS: A Descriptive Catalogue of Manufactures from Native Woods, as shown in the Exhibit of the U. S. Department of Agriculture at the World's Industrial and Cotton Exposition at New Orleans, La. Special Report No. 10, U. S. Dept. Agr., Washington, D. C., 1886, pp. 84.

GOULD, C. W., AND MAXWELL, HU.: The Wood-using Industries of Mississippi. Lumber Trade Journal, March 15, 1912, pp. 19–29.

HALL, WILLIAM L., AND MAXWELL, HU.: Uses of Commercial Woods of the United States: I. Cedars, Cypresses, and Sequoias. Bul. 95, U. S. Forest Service, Washington, D. C., 1911, pp. 62.

————————: Uses of Commercial Woods of the United States: II. Pines. Bul. 99, U. S. Forest Service, Washington, D. C., 1911, pp. 96.

HATCH, CHARLES F.: Manufacture and Utilization of Hickory, 1911. Cir. 187, U. S. Forest Service, Washington, D. C., 1911, pp. 16.

———— AND MAXWELL, HU.: The Wood-using Industries of Missouri. Reprint, St. Louis Lumberman, March 15, 1912, pp. 68–82.

LAZENBY, WILLIAM R.: The Economic Uses of Wood. Pub. Ohio State Univ., Columbus, O., 1904, pp. 14.

MacMillan, H. R.: Wood-using Industries [of Canada], 1910. Bul. No. 24, Forestry Branch, Dept. Int., Ottawa, 1912, pp. 42.

Maxwell, Hu.: The Wood-using Industries of Louisiana. The Lumber Trade Journal, New Orleans, La., Jan. 1, 1912, pp. 19–33.

————: The Wood-using Industries of Maryland. Bul. Maryland State Board of Forestry, Baltimore, Md., 1910, pp. 58.

————: A Study of the Massachusetts Wood-using Industries. Pub. by State of Mass., Boston, 1910, pp. 38.

————: Utilization of Osage Orange. Pub. by Farm Wagon Dept., Nat'l Implement and Vehicle Ass'n., U. S. A., 1911, pp. 14.

Oakleaf, Howard B.: Wood-using Industries of Oregon, with Special Reference to the Properties and Uses of Oregon Woods. Pub. by Oreg. Conservation Ass'n, Portland, Ore., 1911, pp. 46.

————: Washington's Secondary Wood-using Industries. Pacific Lumber Trade Journal, Seattle, 1911, pp. 8.

Simmons, Roger E.: The Wood-using Industries of Illinois. University of Illinois, Urbana, Ill., 1911, pp. 164.

————: A Study of the Wood-using Industries of Kentucky. Pub. by Dept. Agr., Labor and Statistics, Frankfort, Ky., 1910, pp. 74.

————: Wood-using Industries of North Carolina. Econ. Paper No. XX, N. C. Econ. and Geol. Survey, Raleigh, 1910, pp. 74.

Smith, Franklin H.: A Study of the Wisconsin Wood-using Industries. Pub. by Forestry Dept., Madison, Wis., 1910, pp. 68.

Surface, G. T.: The Commercial Woods of the United States and Their Uses. Reprint, Bul. Geog. Soc. of Phila., Vol. VIII, No. 3, July, 1910, pp. 20–34.

## PART II

# KEY TO THE ECONOMIC WOODS OF THE UNITED STATES

### I. Homogeneous or Non-porous Woods: Gymnosperms; Conifers; Softwoods

Vessels absent; wood composed mostly of tracheids uniform in structure and arranged in definite radial rows. Growth rings defined by the greater density of the late wood. Resin cells and resin ducts present or absent. Rays very fine, numerous, inconspicuous.

**A** Resin ducts, both vertical and horizontal, present. Rays with tracheids.

**1** With clear demarcation in color between heartwood and sapwood.

**a** Resin ducts plainly visible to the unaided eye, numerous, often well distributed; tyloses present; epithelium thin-walled. Resin cells absent. Wood with characteristic but not always pronounced resinous odor. **Pine.**[1]

**a**[1] Little contrast between early and late wood. Wood soft to medium; only moderately resinous; texture uniform; color light or reddish, variable. Upper and lower walls of the few and small ray tracheids smooth (Figs. 4–5). Pits present on the tangential walls of the tracheids of the late wood. **Soft Pine Group.**

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Note.—The letters in parentheses following the specific names refer to the map (Plate I, Natural Forest Regions of the United States), and indicate in a general way the distribution of the species.

(P), Pacific Coast Forest; (R), Rocky Mountain Forest; (N), Northern Forest, general; (L), Lake States Forest; (A), Appalachian Forest; (C), Central Hardwood Forest; (S), Southern Forest; (T), Tropical or Subtropical Forest; (n), north; (s), south. Where more than one region is indicated, the more important is placed first.

**a**$^2$ Radial walls of each ray-parenchyma cell with 1–2 large simple pits communicating with each adjacent wood tracheid (Fig. 4). Wood straight-grained; rate of growth widely variable. **White Pine Group.**[2] *Pinus strobus* L. (N); *monticola* Dougl. (P); *lambertiana* Dougl. (P); *flexilis* James (P); *albicaulis* Eng. (R, P); *strobiformis* Eng. (R).

**a**$^3$ Color cream white to reddish brown. Texture fine. Resin ducts fairly conspicuous, appearing on longitudinal surface as straw-colored or light-brown lines. Without sugary exudations. Pits on lateral walls of ray-parenchyma cells large, 1–2 (mostly 1) per tracheid. **White Pine.** *P. strobus* L. (N),[3] *monticola* Dougl. (P).

**b**$^3$ Color yellowish white to very light brown. Texture comparatively coarse. Resin ducts conspicuous, appearing on longitudinal surface as dark lines. Sugary exudations and sugar pockets common. Pits on lateral walls of ray-parenchyma cells comparatively small, 1–2 (mostly 2) per tracheid. **Sugar Pine.** *P. lambertiana* Dougl.(P).[4]

**b**$^2$ The radial walls of each parenchyma cell with 3–6 small semi-bordered pits communicating with each adjacent wood tracheid (Fig. 5). Texture very fine. Wood cross-grained and of very slow growth. **Foxtail and Nut Pine Group.** *P. quadrifolia* Parl. (P); *cembroides* Zucc. (R); *edulis* Eng. (R)[5]; *monophylla* T. & F. (R); *balfouriana* Murr. (P); *aristata* Eng.(P).

**b**$^1$ Decided contrast between early and late wood. Wood very hard to rather soft; resinous; texture uneven; color variable, but mostly darker than in soft pines. Upper and lower walls of the small and numerous ray tracheids dentate or reticulate (Figs. 6, 7). Pits rarely present on tangential walls of the tracheids of the late wood. **Pitch Pine Group.**

**a**$^2$ The radial walls of each ray-parenchyma cell with 1–2 large simple pits communicating with each adjacent wood tracheid (Fig. 6). Wood light, rather soft, fairly strong, medium-textured, not highly resinous.

Growth rings rather wide and uniform. Color light red. Sapwood thin.

**Norway** or **Red Pine.** *Pinus resinosa* Ait. (L).

**b²** The radial walls of each ray-parenchyma cell with 3–6 rather small simple pits communicating with each adjacent wood tracheid (Fig. 7). **Hard Pine Group.**

**a³** Wood mostly heavy, hard, strong, rather tough; unevenly textured. Sapwood variable.

**Southern Pines.*** [6]

**a⁴** Wood usually extremely heavy and hard; very resinous.

**a⁵** Growth rings mostly narrow, uniform in width and outline. Color uniform, dark reddish yellow to reddish brown. Sapwood thin. Parts of wood often becoming "fatty" with resin.

**Longleaf Pine.** *P. palustris* Mill. (S).[7]

**b⁵** Growth rings mostly wide, variable. Dark straw-color with tinge of flesh-color. Sapwood thick.

**Cuban Pine.** *P. heterophylla* (Ell.) Sudw. (S).

**b⁴** Wood of medium weight and hardness. Less resinous than in preceding.

**a⁵** Growth rings mostly of medium width, but variable; often irregular in width and outline. Wood rather variable; fairly hard and strong. Color whitish to reddish brown. Late wood dense. Sapwood widely variable; usually rather thick.

**Shortleaf Pine.** *P. echinata* Mill. (S).

**b⁵** Growth rings widely variable, often extremely broad, irregular, somewhat double. Wood variable from somewhat hard, compact, and strong, to light, coarse, and brashy; late wood often not dense.

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* It is difficult and very often impossible to make specific distinctions in this group by macroscopic inspection, and the microscopic features so far recognized are of little assistance.

Color yellowish to reddish or orange brown. Sapwood very thick.

**Loblolly Pine.** *P. tæda* L. (S).[8]

**b³** Wood comparatively light, soft, not strong, brittle. Texture usually coarse, occasionally medium to fine. Sapwood usually thick; rarely thin. *P. murrayana* "O. C." (R, P); *ponderosa* Laws. (R, P); *radiata* Don. (P)[9]; *attenuata* Lem. (P); *sabiniana* Dougl. (P)[10]; *coulteri* Lamb. (P); *torreyana* Parry (P); *chihuahuana* Eng. (R); *arizonica* Eng. (R); *rigida* Mill. (N); *divaricata* Ait. (N); *pungens* Michx. f. (N); *clausa* Sarg. (S); *glabra* Walt. (S); *virginiana* Mill. (C, S).[11]

**a⁴** Tangential surface showing conspicuous "pebbly" or "bird's-eye" grain. Resin ducts very small, scattering. . Texture fine. Color light yellow or nearly white. Sapwood thin. Properties of wood fairly uniform. **Lodgepole Pine.** *P. murrayana* "O. C." (R, P).

**b⁴** Tangential surface usually normal. Resin ducts comparatively large and numerous. Texture medium to coarse. Color widely variable from pale lemon to orange brown. Sapwood thick. Wood variable from heavy, hard, and coarse to light, soft, fine, and non-resinous like white pine. **Western Yellow Pine.** *P. ponderosa* Laws. (R, P).[12]

**b** Resin ducts mostly inconspicuous, not numerous, irregularly distributed or grouped; chiefly without tyloses; epithelium thick-walled. Resin cells inconspicuous, near the outer limit of the late wood.

**a¹** Resin ducts very small, mostly invisible to unaided eye; round in cross section. Marked contrast in color between heartwood and sapwood. Sapwood thin. Tracheids without spirals.*

**a²** Color yellowish brown. Texture medium.

**Tamarack.** *Larix americana* Michx. (N).

* The occasional occurrence of spirals in the tracheids of the late wood of *Larix* has been noted by Bailey, Bot. Gaz., Vol. XLVIII, pp. 47-55.

**b**[2] Color red to reddish brown. Texture coarse and harsh. **Western Larch.** *L. occidentalis* Nutt. (R).

**b**[1] Resin ducts somewhat larger, usually visible to unaided eye; oval in cross section. Sapwood rather thick. Spiral markings on the tracheids, at least in early wood; marginal ray tracheids with spirals.

**a**[2] Grain usually straight; sometimes wavy. Wood of two kinds: (1) growth rings narrow, wood reddish yellow in color and of fairly uniform texture; rather light and soft, easy to work. (2) Growth rings wide, wood dark red in color and of uneven texture; early wood open and weak, late wood flinty; difficult to work.

**Douglas Fir.** *Pseudotsuga taxifolia* Brit. (P, R).[13]

**b**[2] Grain usually not straight; wood often cross-grained; color always red. Wood usually less dense, rays more numerous, and the pits on the ray-parenchyma cells larger than in the preceding.

**Red Fir.** *P. macrocarpa* Mayr. (P).

**2** Without clear demarcation in color between heartwood and sapwood.

**a** Resin ducts mostly small, scattered; epithelium thick-walled; tyloses often present. Resin cells absent. Tracheids without spirals.* Wood mostly light and soft, fine and even-textured. **Spruce.**[14]

**a**[1] Color white or very light; uniform throughout. Little contrast in density between early and late wood. Resin ducts scarcely visible without lens, being of same color as surrounding wood.

**a**[2] Growth rings mostly wide.†

**White Spruce.** *Picea canadensis* Mill. (N).

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* The sporadic development of wood parenchyma on the outer surface of the late wood, and the occurrence of spiral thickenings of the tracheids in both early and late wood of *Picea* have been noted by Bailey, *loc. cit.*

† Owing to the fact that rate of growth is largely determined by external factors, any attempt to classify woods on a basis of width of ring is at best unsatisfactory and is resorted to here only because constant features of distinction are apparently wanting.

b² Growth rings of medium width, though often very narrow near centre of tree.

**Red Spruce.** *P. rubens* Sarg. (N).

c² Growth rings mostly very narrow throughout.

**Black Spruce.** *P. mariana* Mill. (N).

b¹ Color distinctly reddish, fading gradually outward. Moderate contrast in density between early and late wood; transition gradual. Resin ducts plainly visible to unaided eye, appearing on cross section as white dots against colored background.

**Sitka Spruce.** *P. sitchensis* T. & M. (P).

**B** Resin ducts normally absent; sometimes present as a result of injury, the vertical ducts arranged tangentially in a compact row (Fig. 10). Ray tracheids present or absent.

**1** With clear demarcation in color between heartwood and sapwood.

**a** Resin cells numerous, often conspicuous to unaided eye. Tracheids without spirals. Wood light and soft to moderately so; lustre dull.

a¹ Odorless and tasteless. Texture coarse and harsh. Sapwood thin, straw-colored to nearly white, often streaked with fine purplish lines of resin cells. Resin masses in resin cells appear (under lens) on longitudinal surface as rows of black or amber beads. **Sequoia.**[15]

a² Wood deeply colored, purplish. Growth rings mostly very narrow. Texture fairly coarse.

**Big Tree.** *Sequoia washingtoniana* Sudw. (P).[16]

b² Wood less deeply colored; light cherry. Growth rings variable from wide to narrow. Texture very coarse. Resin masses more prominent than in preceding. **Redwood.** *S. sempervirens* Engl. (P).[17]

b¹ Odor aromatic, pungent. Texture fine to very fine. Sapwood white or nearly so, not streaked. Resin cells small, without bead-like appearance.

a² Growth rings uniform, usually rather wide; late wood rather thin, but very conspicuous; rarely doubled. Resin cells fairly numerous, zonate, mostly in late

wood; usually not visible under lens. Rays 1–8, mostly 3–5, cells high. Texture fine. Color pale reddish brown or roseate. Odor and taste spicy-resinous; characteristic.

**Incense Cedar.** *Libocedrus decurrens* Torr. (P).[18]

**b²** Growth rings usually very irregular in width and outline; often eccentric; late wood usually extremely thin, inconspicuous; very commonly doubled or trebled (Plate II, Fig. 4). Resin cells very numerous, deeply colored, visible under lens; mostly zonate (Plate II, Fig. 3), often giving rise to 1–3 tangential lines visible to unaided eye. Rays 1–20 cells high, very irregular. Texture very fine. Odor aromatic, characteristic. Taste not pronounced.

**Juniper; Cedar.**[19]

**a³** Color deep reddish brown or purple, becoming dull brown upon exposure. **Red Cedar.** *Juniperus virginiana* L. (N, C)[20]; **Southern Red Cedar.** *barbadensis* L. (S); *scopulorum* Sarg. (R).

**b²** Color pale to medium dark brown, usually tinged with red. *J. occidentalis* Hook. (R); *utahensis* Lem. (R); *pachyphlœa* Torr. (Rs); *monosperma* Sarg. (Rs); *californica* Carr. (P).

**b** Resin cells absent. Tracheids with spirals. Woods with high lustre. Odorless and tasteless. Texture fine.

**a¹** Color reddish brown to rose red. Wood heavy, hard, strong, and elastic. Growth rings variable; mostly eccentric; often sinuous. **Yew.**

**a²** Tracheids very small, thick-walled. Color bright orange or rose red; thin sapwood pale yellow. *Taxus brevifolia* Nutt. (P).

**b²** Tracheids larger, rather thin-walled. Color brownish red; thin sapwood nearly white. *T. floridana* Nutt. (S).

**b¹** Color clear bright yellow. Growth rings uniform.

**a²** Wood light, soft, not strong.
**California Nutmeg.** *Tumion californicum* Greene (W).

**b²** Wood heavy, hard, strong.
**Stinking Cedar.** *T. taxifolium* Greene (S).

2 Without clear demarcation in color between heartwood and sapwood.

a Heartwood little if any darker than the sapwood.

a¹ Ray tracheids present. **Hemlock.**

a² Wood harsh and splintery; often knotty and cup shaken; rather cross-grained and not easy to work. Contrast between early and late wood very decided (Plate II, Fig. 2); transition abrupt. Odor rancid. Color light brown with slight reddish hue. Resin cysts normally absent.
**Eastern Hemlock.** *Tsuga canadensis* Carr. (N).

b² Wood rather soft, not splintery; usually clear, free from shake; straight-grained; easy to work. Contrast between early and late wood less decided, and transition more gradual than in preceding. Odorless or somewhat sour. Color very pale brown with pinkish hue to late wood. Resin cysts often present.
**Western Hemlock.** *T. heterophylla* Sarg. (P).[21]

b¹ Ray tracheids absent.* **Fir.**[22]

a² Wood light, soft, weak; growth rings often very wide. Color white or straw, occasionally pale brown in old trees. **White and Balsam Fir Group.** *Abies fraseri* Lindl. (S, A); **Balsam Fir.** *balsamea* Mill. (N); **Alpine Fir.** *lasiocarpa* Nutt. (R); **Lowland Fir.** *grandis* Lindl. (P); **White Fir.** *concolor* Parry (P); *amabilis* Forb. (P).

b² Wood moderately to very heavy, hard, and strong. Color brownish red in general appearance; early wood straw-colored; late wood and rays with reddish tinge. **Red Fir Group. Noble Fir.** *A. nobilis* Lindl. (P); **Red Fir.** *magnifica* Murr. (P).

b Heartwood more deeply colored than the sapwood, fading gradually outward.

a¹ Odorless or slightly rancid; tasteless. Color widely variable; yellowish, reddish, brown, variegated or

* The occasional occurrence of ray tracheids in *Abies balsamea* has been noted by Penhallow, North American Gymnosperms, p. 253.

almost black. Wood variable from light and soft to moderately heavy and hard; often "pecky," *i.e.*, riddled with fungus galleries. Smooth surface of sound wood looks and feels greasy or waxy. Rays numerous, rather prominent; wholly without tracheids. Resin cells numerous and prominent; commonly zonate (Plate II, Fig. 1). Pits on wood tracheids very small, often irregularly disposed; mostly in two rows.

**Bald Cypress.** *Taxodium distichum* Rich. (S).[23]

b¹ Odor resinous or aromatic; agreeable. Tasteless, or with marked resinous flavor. Wood very light and soft.

a² Great variation in depth of color between sapwood and heartwood, that of the latter varying from dark purplish brown to dark brown tinged with red; dark wood often streaked with lighter shades. Sapwood usually dingy white with light shades of brown intermingled. Lustre dull. Odor like oil of cedar; very mild. Tasteless or nearly so. Resin cells present, though often zonate in widely separated growth rings, thus often apparently absent. Rays rather narrow, somewhat prominent; without tracheids.

**Western Red Cedar.** *Thuya plicata* Don. (P).[24]

b² Moderate variation in depth of color between heartwood and sapwood. Resin cells zonate or scattering.

a³ Color light clear yellow, uniform. Odor aromatic, resinous. Taste spicy, very characteristic. Wood light and soft to moderately heavy and hard.

a⁴ Ray tracheids present in low rays. Color very light. Texture very fine. Odor moderately pronounced. **Yellow Cedar.** *Chamæcyparis nootkatensis* Spach. (P).[25]

b⁴ Ray tracheids absent. Color somewhat deeper. Texture moderately fine. Odor very pronounced.

**Port Orford Cedar.** *C. lawsoniana* Parl. (P).[26]

b³ Color pale brown or reddish; intermingling of lighter and darker shades common (esp. in *Thuya occidentalis*). Odor like oil of cedar, but very mild. No pronounced taste. Wood very light and soft,

usually spongy and difficult to cut smoothly across the grain. Rays without tracheids.* **White Cedar.** *C. thyoides* B. S. P. (N, S)[27]; **Arborvitæ.** *Thuya occidentalis* L. (N).[28]

## II. Heterogeneous or Porous Woods: Dicotyledons; Broadleaf Woods; Hardwoods

Vessels present. Wood composed of three to six kinds of elements not uniform in structure and rarely arranged in definite radial rows. Growth rings often defined by zonate arrangement of large pores in early wood as well as by the greater density of the late wood. Resin cells and resin ducts absent. Rays variable from very narow to very broad.

**A** Ring-porous Woods. Pores in early wood zonate, large, and conspicuous, rarely small and inconspicuous; in late wood small or few and scattered. Rays uniseriate or widely variable. Texture medium to very coarse.

**1** Pores in radial lines branching more or less toward the periphery of the growth ring; pores small to very small. Pores in early wood in one to several rows. Wood parenchyma in fine tangential lines.

**a** Broad rays absent; rays uniform, uniseriate, inconspicuous, 5–15 cells high. Wood rather light, moderately soft, stiff but not strong.

**a¹** Pores in early wood few, small, usually round or nearly so, and rather widely separated in a single row. Wood with roseate hue. Odorless and tasteless.
**Western Chinquapin.** *Castanopsis chrysophylla* deC. (P).

**b¹** Pores in early wood very numerous, usually oval or elliptical and in a wide zone. Color brown. Odor very mild. Astringent taste. **Chestnut.** *Castanea dentata* Borkh. (C, N)[29]; **Chinquapin Chestnut.** *pumila* Mill. (S).

**b** Broad rays present; intermediate rays mostly uniseriate, invisible without lens (Plate III, Fig. 1). Wood heavy, hard, strong. Odor characteristic. **Oak.**[30]

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* The occasional occurrence of ray tracheids in the low rays of *C. thyoides* has been noted by Penhallow, North American Gymnosperms, p. 232.

**a**[1] Pores in early wood in few (1–3) rows, usually not crowded; transition to smaller pores of late wood abrupt. Pores in late wood very small, with thin walls and angular outlines (Plate II, Fig. 5); numerous, crowded, not open, appearing as irregular, grayish radial bands widening outward; tyloses abundant in all pores. Large rays often very high, maximum 5 inches. **White Oak Group.**

**a**[2] Radial bands of small pores comparatively broad, more or less fan-shaped, often joined tangentially. **White Oak**. *Quercus alba* L. (C, N) (Frontispiece)[31]; **Bur Oak**. *macrocarpa* Michx. (C, N) (Fig. 14); **Post Oak**. *minor* Sarg. (C, A, S); **Chestnut Oak**. *prinus* L. (N, C)[32]; **Overcup Oak.** *lyrata* Walt. (C, S); **Durand Oak**. *breviloba* Sarg. (S).

**b**[2] Radial bands of small pores comparatively narrow and seldom joined tangentially. **Swamp White Oak.** *Q. platanoides* (Lam.) Sudw. (N, C); **Cow Oak.** *michauxii* Nutt. (C, S).

**b**[1] Pores in early wood mostly in several (3–5) rows, crowded; transition to smaller pores in late wood gradual. Pores in late wood comparatively large, with thick walls and circular outlines (Plate II, Fig. 6); rather few, not crowded, open, usually visible to unaided eye. Tyloses usually scarce or wanting, sometimes abundant (esp. in *Q. marilandica*). Large rays comparatively low, rarely 1 inch high. **Black** or **Red Oak Group.***

**a**[2] Radial bands of small pores comparatively broad, often branched. **Pin Oak**. *Q. palustris* Muench. (C); **Water Oak**. *nigra* L. (S, C); **Shingle Oak**. *imbricaria* Michx. (C, N); **Spanish Oak**. *digitata* Sudw. (S, C); **Turkey Oak**. *catesbæi* Sudw. (S); *marilandica* Muench. (C, S).

**b**[2] Radial bands of small pores narrow, mostly unbranched. **Red Oak.** *Q. rubra* L. (C, N); **Spotted Oak**. *texana* Buckl. (C, S); **Black Oak**. *velutina* Lam.

* For Evergreen Oak group see "Diffuse-porous Woods."

(C, N); **Scarlet Oak**. *coccinea* Muench. (C, N); **Willow Oak**. *phellos* L. (S).

**2** Pores in late wood arranged tangentially in conspicuous festoons or concentric bands, usually continuous, wavy; the pores minute or small. Pores in early wood in single row or in zone of 2–3 (rarely more) rows. Wood parenchyma not in tangential lines.

**a** Rays very distinct; the larger 6–8 cells wide and 30–50 cells high, conspicuous; the smaller 1–2 cells wide and 6–10 cells high, inconspicuous; heterogeneous. Heartwood apparently absent or imperfectly developed. Texture very coarse.

**a¹** Color yellow or grayish yellow.
**Hackberry**. *Celtis occidentalis* L. (C, N, S).

**b¹** Color yellowish green.
**Sugarberry**. *C. mississippiensis* Bosc. (S).

**b** Rays rather indistinct; the larger 3–5 cells wide and 15–30 cells high, appearing much smaller than the larger rays of the preceding; the smaller uniseriate and 3–5 cells high; homogeneous. Heartwood distinct; color brown, often with reddish tinge. Texture medium to coarse. **Elm.**

**a¹** Pores in early wood forming a broad tangential band of 3 or more rows; pores large, numerous, conspicuous. Texture coarse. Wood easy to split. (Inner bark thick, mucilaginous.)
**Slippery Elm**. *Ulmus pubescens* Walt. (C, N, S).

**b¹** Pores in early wood usually in a single tangential row; occasionally more in wide growth rings.

**a²** Pores in early wood large, forming a continuous row (Plate III, Fig. 2). Texture coarse. Wood difficult to split. Rather light.
**White Elm**. *U. americana* L. (C, N).

**b²** Pores in early wood small to minute, the larger ones few and rather widely separated in a band of small pores. Texture medium. Wood hard.

**a³** Growth rings distinct.

**a⁴** Bands of small pores rather few; narrower than intervening spaces. Wood very hard, com-

pact. Fairly easy to split. **Rock** or **Hickory Elm.** *U. racemosa* Thomas (C, N).

b⁴ Bands of small pores numerous; wider than intervening spaces. Wood moderately hard. Difficult to split.

**Winged Elm.** *U. alata* Michx. (S, C).

b³ Growth rings indistinct. Bands of small pores broad, very wavy, and branched. Wood hard. Difficult to split.

**Cedar Elm.** *U. crassifolia* Nutt. (S).

3 Pores in late wood small, distributed singly, in groups, or in mostly short, broken (occasionally continuous) more or less tangential lines. Rays fairly uniform, fine to minute. Wood parenchyma around pores or extending wing-like from pores in late wood, often uniting them into irregular tangential lines. Outer limit of growth ring consists chiefly or exclusively of wood parenchyma.

**a** Pores in early wood very small, indistinct, rather widely separated in a single row. Wood very light, soft, weak, difficult to cut smoothly across the grain.

**Water Ash.** *Fraxinus caroliniana* Mill. (S).

**b** Pores in early wood large, conspicuous, usually in a rather broad zone 3–10, rarely 1–2, rows wide.

**a¹** Rays narrow (1–5 cells), inconspicuous; almost invisible on cross section to unaided eye. Color pale or dull brown to nearly white; not very deep or striking.

**a²** Odorless and tasteless. Medium to very heavy and hard. Pores in late wood isolated, or in groups of 2–3, or united by wood parenchyma into mostly short tangential lines, especially in outer portion of growth ring. Color brown to white, sometimes with reddish tinge to late wood. Sapwood very thick, white. Demarcation in color between heartwood and sapwood not clear. Rays homogeneous. **Ash.**

**a³** Pores in late wood usually joined tangentially by wood parenchyma. Wood very hard and strong.

**a⁴** Pores in early wood in rather broad zone; numerous.

**a⁵** Lines of pores in late wood short, narrow, composed of few open pores and considerable wood parenchyma; mostly near periphery of growth ring; occasionally absent or very indistinct in narrow rings.
**White Ash.** *Fraxinus americana* L. (C, N).

**b⁵** Lines of pores in late wood long, narrow, prominent, composed of abundant wood parenchyma and inconspicuous pores; usually well distributed. **Blue Ash.** *F. quadrangulata* Michx. (C); **Red Ash.** *pennsylvanica* Marsh. (N).

**b⁴** Pores in early wood in rather narrow zone; not numerous. Lines of pores in late wood quite long and conspicuous; well distributed.
**Green Ash.** *F. lanceolata* Borkh. (C, N, S).

**b³** Pores in late wood rarely joined by wood parenchyma. Wood of medium hardness and strength.

**a⁴** Pores in early wood in very broad zone, commonly one-half the width of the growth ring. Pores in late wood isolated, few, large. Color dark brown. Wood comparatively soft and weak. Ray cells small. **Black Ash.** *F. nigra* Marsh. (C, N) (Plate V, Fig. 2).

**b⁴** Pores in early wood in zone of medium width, commonly one-third the width of the growth ring. Pores in late wood in radial groups of 2–5 and near periphery of growth ring somewhat tangentially grouped. Color light brown; sapwood with reddish tinge. Wood harder and stronger than preceding. Ray cells large.
**Oregon Ash.** *F. oregona* Nutt. (P).

**b²** Odor characteristic; somewhat resembling that of kerosene. Tasteless. Wood very light and soft. Pores in late wood in rather large groups and near periphery of growth ring in broad, comparatively short (sometimes continuous) tangential bands; in very wide rings pores often indistinctly grouped. Color light to medium dark brown, satiny; very

thin sapwood lighter. Demarcation in color between heartwood and sapwood distinct. Rays heterogeneous. **Common Catalpa.** *Catalpa catalpa* Karst. (C, S); **Hardy Catalpa.** *speciosa* Ward. (C).[33]

**b¹** Rays narrow (1–3 cells), very fine but fairly distinct. Color light orange brown.

**a²** Odor aromatic or spicy, usually quite pronounced. Often with characteristic pleasant taste (most pronounced in inner bark). Wood light and soft. Pores in late wood in numerous small groups radially, and toward periphery of growth ring tangentially, elongated. Sapwood very thin, nearly white. Clear demarcation in color between heartwood and sapwood. Occasional marginal cells very large, ovate or round; rays heterogeneous (Fig. 3, A).

**Sassafras.** *Sassafras sassafras* Karst. (S, C).[34]

**c¹** Rays variable, but usually quite distinct, mostly 5–9 cells wide. Color of wood variable, but usually deep and striking.

**a²** Color golden yellow to greenish brown; very thin sapwood white or greenish. Wood extremely hard (like horn), very heavy and strong. Texture fine. Vessels densely plugged with tyloses. Pores in early wood in comparatively narrow zone, irregular, interspersed with abundant wood parenchyma. Pores in outer portion of late wood in large groups joined tangentially by wood parenchyma. Rays heterogeneous.

**a³** Color always golden yellow, though darkening upon exposure; vertically streaked with narrow red stripes. Color slightly soluble in water. Lustre high. Wood tasteless. Rays fine, numerous, rather inconspicuous. **Osage Orange.** *Toxylon pomiferum* Raf. (C, S) (Plate III, Fig. 4).[35]

**b³** Color varying from golden yellow to brown, often greenish, usually uniform in single specimen; rarely striped with red. Color of golden yellow wood readily soluble in water, wet wood giving off stain when applied to white paper or cloth.

Lustre not so high as in preceding. Taste of wood "leguminous." Rays variable from minute to medium, irregular, rather conspicuous. **Black Locust.** *Robinia pseudacacia* L. (C, A) (Plate III, Fig. 3).[36]

$b^2$ Color orange yellow to yellowish brown, becoming russet brown upon exposure; thin sapwood nearly white. Wood moderately heavy, hard, and strong. Texture coarse. Pores in early wood often in rather wide zone. Pores in late wood minute, in groups of 3–6; not joined by wood parenchyma. Tyloses present, fairly abundant. Rays very prominent on radial section, often high; heterogeneous. Odorless and tasteless. **Red Mulberry.** *Morus rubra* L. (C, S) (Plate V, Fig. 1).

$c^2$ Color light cherry red to reddish brown; thin to moderately thick sapwood greenish. Wood heavy, hard, and strong. Texture very coarse. Pores in early wood in broad zone. Tyloses absent or rare. Gummy substance in vessels. Odorless and tasteless. Rays mostly homogeneous.

$a^3$ Rays distinct, but not conspicuous; fairly uniform; ray cells very small, uniform. Pores in outer portion of late wood small to minute, usually in groups of 5–20; rarely joined by wood parenchyma into bands; individual pores visible under lens. **Kentucky Coffee Tree.** *Gymnocladus dioicus* Koch (C) (Plate III, Fig. 5).

$b^3$ Rays conspicuous; variable; ray cells comparatively large, variable. Pores in outer portion of late wood minute; usually in groups of 10–25; often joined by wood parenchyma into short, wavy (sometimes continuous) tangential bands; individual pores mostly invisible under lens. **Honey Locust.** *Gleditsia triacanthos* L. (C, S) (Plate III, Fig. 6).

4 Pores in late wood isolated or fairly evenly distributed; not in groups or lines; comparatively large, often approaching in size those of early wood. Pores in early wood moderately

large, not abundant, usually in very irregular zone; in narrow growth rings rather diffuse. Rays fairly uniform, not conspicuous, abundant. Wood parenchyma in fine tangential lines.

**a** Wood elements in tier-like arrangement (Plate IV, Figs. 4, 5), producing on longitudinal surface fine, wavy cross-markings readily visible to unaided eye. Lines of wood parenchyma indistinct, finer than the rays (Plate IV, Fig. 2). Crystals present, rather small; mostly in long rows. Rays in stories; fairly uniform in height; 1–2 (rarely 3) seriate; cells large (Plate IV, Fig. 4). Color of wood of old trees dark brown to black; thick sapwood (making up all or nearly all of young trees) yellowish, usually streaked with black. Wood fibres thick-walled. Wood very heavy, hard, and strong. Tyloses absent. **Persimmon.** *Diospyros virginiana* L. (S, C).

**b** Wood elements not in tier-like arrangement. Lines of wood parenchyma as distinct as the rays. Crystals large; usually solitary. Rays irregularly disposed; not uniform in height or shape; 1–5 seriate; cells small (Plate IV, Fig. 3). Color of wood brown to reddish brown; thick sapwood white, often with dark reddish streaks. Tyloses present. **Hickory.**[38]

**a¹** Wood very hard, heavy, tough, strong, resilient. Wood fibres very thick-walled. **Shagbark.** *Hicoria ovata* Brit. (C, N) (Plate IV, Fig. 3); **Shellbark.** *laciniosa* Sarg. (C); **Mocker Nut.** *alba* Brit. (C, N, S); **Pignut.** *glabra* Brit. (C, N, S).

**b¹** Wood hard, heavy, brittle, fairly strong. Wood fibres comparatively thin-walled.

**a²** Growth rings not clearly defined. Large pores not in well-defined zone; scattered; approaching diffuse-porous. **Water Hickory.** *H. aquatica* Brit. (S).

**b²** Growth rings clearly defined. Large pores in fairly well-defined zone, 1–several pores wide. **Pecan.** *H. pecan* Brit. (S, C); **Nutmeg Hickory.** *myristicæformis* Brit. (S); **Bitternut.** *minima* Brit. (C, N, S).

**B** Diffuse-porous Woods. Pores numerous; usually not prominent on cross section; diffused throughout growth ring instead

of collected in decided ring or zone in the early wood; occasionally more numerous and very often somewhat larger in the early wood. Growth rings principally defined by the greater density of the late wood or by the radial flattening of the outermost rows of wood fibres; often indistinct; sometimes absent.

**1** Growth rings absent or indistinct; when present not corresponding to annual periods and not separable into early and late wood.

**a** Broad rays present.

**a¹** Color light to dark brown, sometimes tinged with red. Wood very heavy, hard, strong, and tough; not easy to work. Pores slightly variable in size; rather small but distinct, arranged in radial rows or groups usually continuous from year to year. Large rays mostly rather low, broad; often appearing on tangential surface as aggregations of small rays interspersed with wood fibres. **Evergreen Oak Group.**[39]

**a²** Wood parenchyma in very distinct tangential lines. **Tanbark Oak.** *Quercus densiflora* H. & A. (P)[40]; *hypoleuca* Eng. (Rs).

**b²** Wood parenchyma not in tangential lines or, if so, not distinct. **Live Oaks.** *Q. virginiana* Mill. (S), *chrysolepis* Liebm. (Ps), *agrifolia* Nee. (Ps).

**b** Broad rays absent.

**a¹** Color rich reddish brown to light brown; widely variable. Wood variable from light and soft to very hard, heavy (sp. gr., .56–.88), and strong; brittle; often highly figured. Pores uniform in size, rather large and conspicuous, equally distributed, solitary or in radial groups of 2–3; often filled with dark-red resin. Rays fine but distinct, producing silver grain on radial surface; deeply colored; heterogeneous; often in horizontal seriation producing rather undulating cross lines on tangential surface. Wood parenchyma in rather widely separated conspicuous tangential lines, limiting growth rings. **Mahogany.** *Swietenia mahagoni* Jacq. (T).[41]

**b¹** Color dark yellowish brown with decided greenish tinge, often streaked; nearly black in old trees. Wood ex-

ceedingly heavy (sp. gr., 1.14), harder than horn, strong, brittle, cross-grained, very difficult to work. Pores somewhat variable in size, small and inconspicuous, scattered, solitary; usually filled with dark-green resin. Rays very fine, uniseriate, deeply colored, almost invisible; in perfect horizontal series, producing cross lines very distinct under lens. Wood parenchyma in numerous, fine, wavy tangential lines.

**Lignumvitæ.** *Guaiacum sanctum* L. (T).

**c¹** Color light brown or straw. Wood very hard (sp. gr., .83), heavy, tough, and strong like hickory; fibres much interlaced; wood rather difficult to work. Pores variable in size, conspicuous, irregularly distributed in wavy lines or groups, open. Alternate bands of very dense and less dense wood produce zones somewhat resembling annual rings. Rays very fine, not deeply colored, almost invisible; irregularly distributed. Wood parenchyma not in tangential lines.

**Blue Gum.** *Eucalyptus globulus* Lab. (Ps, T).[42]

**2** Growth rings usually distinct, corresponding to annual periods; late wood recognized by its greater density, tangential flattening of the outermost rows of fibres, and somewhat fewer or smaller pores.

**a** Pores comparatively large in early wood, distinct to unaided eye, diminishing in size and number toward periphery of growth ring; often approaching ring-porous.

**a¹** Rays fine, 1–4 seriate, few to 30 cells high, scarcely visible to unaided eye; mostly homogeneous. Pores solitary or in radial groups of 2–5; often in diagonal rows. Vessels without spirals; tyloses present, very dark-colored. Wood parenchyma in numerous, very fine, short, tangential lines; chambered cells bearing crystals common (Plate IV, Fig. 6).

**a²** Wood heavy and hard, moderately stiff and strong. Odor mild, but characteristic. Color rich dark or chocolate brown. Sapwood rather thin to thick.

**Black Walnut.** *Juglans nigra* L. (C, A).[41]

**b**$^2$ Wood light, soft, not strong. Odorless. Color light chestnut brown with dark tangential zones. Sapwood very thin. **Butternut.** *J. cinerea* L. (C, N).[43]

**b** Pores very small to minute, indistinct, usually fairly uniform in size and distribution throughout growth ring.

**a**$^1$ With conspicuously broad rays.

**a**$^2$ Broad rays rather few, appearing as aggregated small rays (Plate V, Figs. 3, 4). Wood without "silver grain."

**a**$^3$ Broad rays grouped, confined to short radii. Intermediate rays abundant, very fine, indistinct, irregular. Wood parenchyma in indistinct tangential lines. Pores in early wood arranged radially or obliquely; not crowded; near periphery of growth ring minute and sometimes in groups which appear to unaided eye as white dots. Vessels with spirals. Growth rings decidedly undulating. Color yellowish white. Wood heavy, hard, very tough, difficult to split.
**Blue Beech.** *Carpinus caroliniana* Walt. (N, C).[44]

**b**$^3$ Broad rays distant, fairly evenly distributed. Intermediate rays very numerous, uniseriate, invisible to unaided eye. Wood parenchyma not in tangential lines. Pores more numerous in early wood, showing slightly radial arrangement; somewhat crowded. Vessels without spirals. Growth rings not undulating or only slightly so; not very clearly defined. Color light brown tinged with red; exposed surface of lighter colored sapwood soon stained reddish brown upon exposure. Wood light, soft, moderately strong, brittle. **Red Alder.** *Alnus oregona* Nutt. (P) (Plate V, Figs. 3, 4).[45]

**b**$^2$ Broad rays numerous, non-aggregated. Wood with conspicuous "silver grain" on radial surface.

**a**$^3$ Rays practically all broad, mostly 10–15 cells; abundant; fairly regularly disposed; of deeper color than surrounding tissue, producing very conspicuous "silver grain"; homogeneous. Wood

parenchyma in indistinct tangential lines. Pores crowded. Color light brown, often with dark stripes or "feather grain." Wood medium to heavy, moderately hard, usually cross-grained, difficult to split. **Sycamore or Buttonball.** *Platanus occidentalis* L. (C, N, S), *racemosa* Nutt. (Ps), *wrightii* Wats. (Rs).

b³ With only part of the rays broad; variable; irregularly distributed; intermediate rays visible, mostly uniseriate; heterogeneous. "Silver grain" less conspicuous than in preceding. Wood parenchyma in indistinct tangential lines. Pores crowded. Color pale reddish brown to white with reddish tinge; uniform. Wood heavy, hard, strong, usually fairly straight-grained.
**Beech.** *Fagus americana* Sw. (C, N, S).

b¹ Without conspicuously broad rays.

a² Rays very distinct; variable, 1–7 cells wide.

a³ Wood fibres with spirals.

a⁴ Color chalky white. Pores irregularly distributed in long radial lines. Vessels with spirals; perforations scalariform. Rays colorless; heterogeneous. Wood parenchyma not in distinct lines. Wood of medium weight, hard and tough. **Holly.** *Ilex opaca* Ait. (S, C).

b³ Wood fibres without spirals.

a⁴ Wood parenchyma not in tangential lines. Vessels with spirals; perforations simple.

a⁵ Color rich reddish brown or vinous. Pores numerous, solitary, or in groups, often radial, of 2–6; usually more abundant in early wood, producing a light-colored line of demarcation between growth rings. Vessels plugged at intervals with dark red gum. Rays mostly 3–5 cells wide, occasionally uniseriate; few to 100 cells high; producing fine but conspicuous "silver grain" on radial surface. Wood moderately heavy, hard, and strong.

**Black Cherry.** *Prunus serotina* Ehrh. (C, N, S).

**b**[5] Color light brown tinged with red to decidedly reddish. Pores not crowded, fairly evenly distributed; solitary or in radial groups of 2–3. Rays with considerable red color; homogeneous. Grain often curly, "landscape," or "bird's-eye." **Maple.**[46]

**a**[6] Part of the rays comparatively large, 5–7 cells wide, broader than the pores; high, conspicuous. Intermediate rays mostly uniseriate. Pith flecks rare. Growth rings very distinct. Wood very heavy, hard, and strong. **Sugar Maple.** *Acer saccharum* Marsh. (N, C); **Black Maple.** *nigrum* Michx. (N, C).

**b**[6] With less variation in size of rays, the large ones not as broad as the pores; low, inconspicuous; few uniseriate rays. Growth rings often indistinct.

**a**[7] Color deep and rich. Pith flecks uncommon. Wood fairly heavy, hard and strong. *A. macrophyllum* (P).

**b**[7] Color pale. Pith flecks very common, often abundant. Wood rather light, soft, fairly strong. **Red Maple.** *A. rubrum* L. (N, C, S); **Silver Maple.** *saccharinum* L. (N, C, S).

**c**[5] Color creamy or yellowish white, without reddish tinge. Pores very small and numerous; often in radial groups of 2–6. Rays without color; finer and more numerous than in preceding. Wood light, soft, not strong. Otherwise as in preceding. **Box-elder.** *A. negundo* L. (N, C, S, R), *negundo californicum* Sarg. (Ps).

**b**[4] Wood parenchyma in somewhat broken tangential lines, scarcely visible with lens.

**$a^5$** Wood elements not in tier-like arrangement. Vessels without spirals; perforations scalariform; often with scalariform bordered pits. Rays light red or pink in color; heterogeneous. Color pale reddish brown or pinkish, sometimes with greenish hue. Wood very heavy, hard and tough. **Dogwood.**

**$a^6$** Rays 1–7 cells wide, few to 80 cells high. *Cornus florida* L. (N, C, S).

**$b^6$** Rays smaller, 1–4 cells wide, few to 40 cells high. *C. nuttallii* Aud. (P).

**$b^5$** Wood elements (except rays) in tier-like arrangement, producing somewhat indistinct cross-markings on longitudinal surface. Vessels with spirals; perforations mostly simple; bordered pits not scalariform. Rays colorless, widely variable in size; small rays uniseriate, 10–15 cells high; large rays, 3–5 cells wide, 50–100 cells high; homogeneous. Color light brown to nearly white. Wood light, soft, compact, moderately strong. **Basswood.**[47] *Tilia americana* L. (N, C), *pubescens* Ait. (S, C), *heterophylla* Vent. (A, C, S).

**$b^2$** Rays distinct; fairly uniform in width, 1–3-seriate.

**$a^3$** Wood with straight grain, usually light and soft, easy to work. Wood fibres with rather thin walls, usually rounded; not in radial rows. Pores crowded; tyloses absent. Outer limit of growth ring composed of 2–4 rows of tangentially flattened wood-parenchyma fibres with very thick radial walls. Rays heterogeneous.

**$a^4$** Vessels with round or elliptical bordered pits; without spirals. Pores rarely in radial groups. Rays mostly 3-seriate, few to 60, mostly 20–40, cells high. Texture fine. Color variable from deep iridescent blue to the more common yellowish brown; often striped. **Yellow Poplar** or

**Tulip-tree.** *Liriodendron tulipifera* L. (C, N) (Plate VI, Figs. 2, 4).[48]

$b^4$ Vessels with abundant scalariform bordered pits (Plate VI, Fig. 3); with spirals, though often indistinct. Pores often in radial groups of 3–8.

$a^5$ Rays crowded on cross section, conspicuous; 2–3-seriate, mostly 50–100 cells high. Pores very crowded. Texture coarse. Color light brown.

**Sweet Bay.** *Magnolia glauca* L. (S).

$b^5$ Rays not crowded on cross section, inconspicuous; nearly always biseriate and usually 10–15 cells high. Pores moderately crowded. Texture fine. Color usually as in *Liriodendron*. **Cucumber Tree.** *M. acuminata* L. (C, A) (Plate VI, Fig. 3).

$b^3$ Wood with cross or interlocked grain, rather heavy, moderately hard, difficult to work; fine-textured. Wood fibres with thick walls, mostly square; in rather definite radial rows. Pores very numerous, uniformly distributed. Vessels rather sparsely pitted, often with scalariform bordered pits; spirals confined to constricted ends of segments, inconspicuous; tyloses present. Wood-parenchyma fibres few, scattered. Rays heterogeneous; very fine, 1–2-seriate, few to 30 cells high; resinous. Color reddish brown, usually with irregular dark streaks producing "watered" effect on smooth longitudinal surface. **Red** or **Sweet Gum.** *Liquidambar styraciflua* L. (C, S) (Plate VI, Fig. 1).[49]

$c^2$ Rays mostly indistinct to unaided eye, variable, 1–7-seriate.

$a^3$ Pores comparatively few, widely variable in size, mostly in irregularly branching radial lines; near periphery of growth ring minute and in groups which appear to unaided eye as white dots. Vessels with numerous, rather large bordered pits;

with spirals; perforations simple. Rays 1–2, occasionally 3, seriate; few to 20, occasionally 40, cells high. Wood parenchyma in indistinct tangential lines barely visible with lens. Growth rings sinuous, quite distinct. Color light brown; sapwood with pinkish hue. Wood very heavy, hard, tough, difficult to split. **Hornbeam.** *Ostrya virginiana* Koch. (N, C) (Plate V, Fig. 6).

**b**³ Pores numerous, fairly uniform in size and distribution throughout growth ring, solitary or in radial groups of 2–6. Vessels without spirals; perforation scalariform. Rays variable. Growth rings regular in outline.

**a**⁴ Wood straight-grained, fissile, easy to work. Growth rings usually distinct. Vessels densely pitted with extremely small bordered pits with slit-like openings. Rays homogeneous. Wood parenchyma scattered, sometimes in broken tangential lines in outer late wood.

**a**⁵ Rays 1–5-seriate, occasionally wider. Pores usually distinct to unaided eye.

**a**⁶ Wood heavy, hard, and strong. Pores moderately abundant. Wood fibres with thick walls. Rays widest of genus, deeply colored. Pith flecks rare. Color brown tinged with red, often deep and handsome. **Sweet, Black,** or **Cherry Birch.** *Betula lenta* L. (N, C) (Plate V, Fig. 5).

**b**⁶ Wood rather light and soft, moderately strong. Pores very numerous, larger than in preceding. Wood fibres with rather thin walls. Pith flecks common. Color brown. **Red** or **River Birch.** *B. nigra* L. (S, C, N).

**b**⁵ Rays 1–2, sometimes 3, seriate. Pores very small, indistinct to unaided eye.

**a**⁶ Wood rather heavy, hard, and strong. Pores moderately abundant. Sapwood thin, light brown or yellowish. Pith

flecks rare. **Yellow Birch.** *B. lutea* Michx. f. (N, C).

b[6] Wood light and soft, not strong. Sapwood thick, white. Pith flecks usually abundant. **Paper Birch.** *B. papyrifera* Marsh. (N, Rn, Pn).[50] **Gray Birch.** *populifolia* Marsh. (N).

b[4] Wood cross-grained, tough to split, difficult to work. Growth rings usually indistinct. Vessels sparsely to densely pitted with moderately large bordered pits sometimes scalariform. Rays heterogeneous; 1–5 cells wide, few to 40 cells high. Wood parenchyma mostly around vessels, not in tangential lines. Color brown to nearly white.

a[5] Rays mostly 1–2-seriate (sometimes wider). Pores numerous, usually evenly distributed.

a[6] Pores of medium size. Wood fibres with rather thin walls and large lumina. Wood light (sp. gr., .54), soft, not strong. **Tupelo.** *Nyssa aquatica* L. (S, C).[51]

b[6] Pores small. Wood fibres with thick walls and small lumina. Wood comparatively heavy (sp. gr., .64), hard and strong. **Black Gum.** *N. sylvatica* Marsh. (C, N, S).

b[5] Rays mostly 3–4-seriate. Pores comparatively large, not very numerous, unevenly distributed. Wood fibres with thin walls and large lumina. Wood light (sp. gr., .53), soft, not strong. **Sour Tupelo.** *N. ogeche* Marsh. (S).

d[2] Rays very fine, indistinct, uniseriate.

a[3] Growth rings limited by 1–2 rows of thin wood-parenchyma fibres. Pores very numerous. Vessels densely pitted; perforations simple. Wood light and soft.

a[4] Rays distinct under lens, mostly 10–12 cells high. Pores minute, invisible to unaided eye,

mostly solitary, uniformly distributed. Vessels with spirals. Color pale yellow to nearly white. Lustrous. Texture very fine and uniform. Grain often wavy and somewhat interlocked.

**a**[5] Wood elements (including rays) in tier-like arrangement, producing very distinct transverse lines on longitudinal surface.
**Buckeye.** *Æsculus octandra* Marsh. (C).[52]

**b**[5] Wood elements not in tier-like arrangement. **Ohio Buckeye.** *A. glabra* Willd. (C) (Plate VI, Figs. 5, 6); **California Buckeye.** *californica* Nutt. (Ps).

**b**[4] Rays indistinct under lens; 1–25, mostly 10–15, cells high. Pores variable; in short radial groups. Vessels without spirals. Grain usually straight.

**a**[5] Rays heterogeneous. Pores small to minute, those in early wood readily visible to unaided eye. Color pale reddish brown. Lustre dull. **Black Willow.** *Salix nigra* Marsh. (N, S, C, Rs, Ps).[53]

**b**[5] Rays homogeneous.

**a**[6] Pores minute, invisible without lens. Texture very fine. Lustre silky. Color light brown to silvery white. **Aspen.** *Populus tremuloides* Michx. (N, C, R, P).[54] **Large Tooth Aspen.** *grandidentata* Michx. (N, C).

**b**[6] Pores small to minute, those in early wood usually visible to unaided eye. Texture coarse. Lustre dull. Color pale, dull brown, or grayish brown. **Cottonwood.** *P. heterophylla* L. (S, C), *trichocarpa* T. & G. (P), *deltoides* Marsh. (N, C, S, R).

## REFERENCES

[1]*Pine:*

BAILEY, IRVING W.: The Structure of the Wood in the Pineæ. Bot. Gaz., Vol. XLVIII, July 1909, pp. 47–55.

BAILEY, IRVING W.: Anatomical Characters in the Evolution of Pinus. Am. Naturalist, Vol. XLIV, May 1909, pp. 284–293.

HALL, WILLIAM L., AND MAXWELL, HU.: Uses of the Commercial Woods of the United States, II. Pines. Bul. 99, U. S. Forest Service, 1911.

BURGERSTEIN, ALFRED: Vergleichende anatomische Untersuchungen des Fichten- und Lärchenholzes. Denkschrift f. kaiserl. Acad. wissensch. Math.-Natur. Classe, Vol. LIX, No. 6, 1894, pp. 214–215.

[2]*White Pine Group:*

ROCKWELL, F. I.: The White Pines of Montana and Idaho—Their Distribution, Quality and Uses. For. Quarterly, Vol. IX, No. 2, 1911, pp. 219–231.

[3]*Pinus strobus:*

SPALDING, V. M.: The White Pine. Bul. 22, U. S. Div. Forestry, 1899.

[4]*Pinus lambertiana:*

COOPER, ALBERT W.: Sugar Pine and Western Yellow Pine in California. Bul. 69, U. S. Forest Service, 1906.

[5]*Pinus edulis:*

PHILLIPS, F. J.: A Study of Piñon Pine. Bot. Gaz., Vol. XLVIII, Sept. 1909, pp. 216–223.

HELLER, A. A.: The Nut Pine. Muhlenbergia, Vol. V, 1909, pp. 31–35.

[6]*Southern Pines:*

FERNOW, B. E.: Southern Pine: Mechanical and Physical Properties. Cir. 12, U. S. Div. Forestry, 1896.

MOHR, CHARLES, AND ROTH, FILIBERT: The Timber Pines of the Southern United States, together with a Discussion of the Structures of their Wood. Bul. 13 (rev. ed.), U. S. Div. Forestry, 1897.

BETTS, H. S.: Properties and Uses of the Southern Pines. Cir. 164, U. S. Forest Service, 1909.

[7]*Pinus palustris:*

FERNOW, B. E.: Timber Physics, Part II, Results of Investigations on Longleaf Pine. Bul. 8, U. S. Div. Forestry, 1893.

BITTING, KATHERINE G.: The Histological Difference between Pinus tæda and Pinus palustris. Proc. Ind. Acad. Sci., Indianapolis, Ind., 1908, pp. 127–129.

[8]*Pinus tæda:*

ZON, RAPHAEL: Loblolly Pine in Eastern Texas. Bul. 64, U. S. Forest Service, 1905.

HATT, W. KENDRICK: Second Progress Report on the Strength of Structural Timber. Cir. 115, U. S. Forest Service, 1907.

[9]*Pinus radiata:*

ALBERT, F.: El Pino de Monterei, Pinus insignus o mejor Pinus radiata. Santiago de Chili Min. Indust., 1908.

[10]*Pinus sabiniana:*

SHINN, CHARLES H.: Economic Possibilities of Pinus sabiniana. Proc. Soc. Am. Foresters, Vol. VI, No. 1, 1911, pp. 68–77.

[11]*Pinus virginiana:*

STERRETT, W. D.: Scrub Pine. Bul. 94, U. S. Forest Service, 1911.

[12]*Pinus ponderosa:*

COOPER, ALBERT W.: Sugar Pine and Western Yellow Pine in California. Bul. 69, U. S. Forest Service, 1906.

WOOLSEY, THEODORE S., JR.: Western Yellow Pine in Arizona and New Mexico. Bul. 101, U. S. Forest Service, 1911.

[13]*Pseudotsuga taxifolia:*

CLINE, MCGARVEY, AND KNAPP, J. B.: Properties and Uses of Douglas Fir. Bul. 88, U. S. Forest Service, 1911.

FROTHINGHAM, E. H.: Douglas Fir: A Study of the Pacific Coast and Rocky Mountain Forms. Cir. 150, U. S. Forest Service.

[14]*Spruce:*

HODSON, E. R., AND FOSTER, J. H.: Engelmann Spruce in the Rocky Mountains. Cir. 170, U. S. Forest Service, Washington, D. C., 1910.

JEFFREY, EDWARD C.: The Comparative Anatomy and Phylogeny of the Coniferales, Part II, Abietineæ. Mem. Boston Soc. Nat. History, Vol. VI, No. 1, Boston, 1905.

BASTIN, E. S., AND TRIMBLE, H.: A Contribution to the Knowledge of North American Coniferæ. Amer. Journal Pharm., Vol. LXVIII, No. 8, 1896, pp. 409–422.

[15]*Sequoia:*

HALL, WILLIAM R., AND MAXWELL, HU.: Uses of Commercial Woods of the United States. I. Cedars, Cypresses, and Sequoias. Bul. 95, U. S. Forest Service, 1911, pp. 57–62.

JEFFREY, EDWARD C.: The Comparative Anatomy and Phylogeny of the Coniferales. Part I, The Genus Sequoia. Mem. Boston Soc. Nat. History, Vol. V, No. 10, pp. 441–459.

JEFFREY, EDWARD C.: A Fossil Sequoia from the Sierra Nevada. Bot. Gaz., Vol. XXXVIII, No. 5, pp. 321–332.

[16]*Sequoia washingtoniana:*

A Short Account of the Big Trees of California. Bul. 28, U. S. Div. Forestry, 1910.

[17]*Sequoia sempervirens:*

FISHER, RICHARD T., ET AL: The Redwood. Bul. 38, U. S. Bu. Forestry, 1903.

GORDON, MARJORIE: Ray Tracheids in Sequoia sempervirens. New Phytologist, Vol. XI, No. 1, Jan. 1912, pp. 1–7.

[18]*Libocedrus decurrens:*

HALL AND MAXWELL: *loc. cit.*, pp. 31–33.

[19]*Juniper: Cedar:*

HALL AND MAXWELL: *loc. cit.*, pp. 11–31.

[20]*Juniperus virginiana:*

Mohr, Charles: Notes on the Red Cedar. Bul. 31, U. S. Bu. Forestry, 1901.

White, L. L.: Production of Red Cedar for Pencil Wood. Cir. 102, U. S. Forest Service, 1907.

[21]*Tsuga heterophylla:*

Allen, Edward T.: The Western Hemlock. Bul. 33, U. S. Bu. Forestry, 1902.

Oakleaf, Howard B.: Wood-using Industries of Oregon. Pub. by Oregon Conservation Assn., Portland, Ore., 1911, pp. 29–30.

[22]*Fir:*

Thompson, W. P.: Ray Tracheids in Abies. Bot. Gazette, Vol. LIII, No. 4, Apr. 1912, pp. 331–338.

Bastin, E. S., and Trimble, H.: A Contribution to the Knowledge of the North American Coniferæ. Amer. Journal Pharm., Vol. LXVIII, No. 10, 1896, pp. 554–566.

[23]*Taxodium distichum:*

Roth, Filibert: Progress in Timber Physics: Bald Cypress (Taxodium distichum). Cir. 19, U. S. Div. Forestry, 1898.

Hall and Maxwell: *loc. cit.*, pp. 41–47.

[24]*Thuya plicata:*

Hall and Maxwell. *loc. cit.*, pp. 36–41.

[25]*Chamæcyparis nootkatensis:*

Hall and Maxwell: *loc. cit.*, pp. 35–36.

[26]*Chamæcyparis lawsoniana:*

Hall and Maxwell: *loc. cit.*, pp. 33–35.

[27]*Chamæcyparis thyoides:*

Hall and Maxwell: *loc. cit.*, pp. 12–16.

[28]*Thuya occidentalis:*

Hall and Maxwell: *loc. cit.*, pp. 16–19.

[29]*Castanea dentata:*

Ashe, W. W.: Chestnut in Tennessee. Bul. 10, B, Tenn. Geol. Survey, Nashville, 1912.

Zon, Raphael: Chestnut in Southern Maryland. Bul. 53, U. S. Bu. Forestry, 1904.

Lavaille, J. B.: Le Chataignier. Paris, 1906.

[30]*Oak:*

Sudworth, George B., and Mell, C. D.: The Identification of Important North American Oak Woods. Bul. 102, U. S. Forest Service, 1911.

Bailey, Irving W.: Notes on the Wood Structure of Betulaceæ and Fagaceæ. Forestry Quarterly, Vol. VIII, No. 2, 1910.

Bailey, Irving W.: On the Origin of the Broad Ray in Quercus. Bot. Gaz., Vol. XLIX, No. 3, March 1910, pp. 161–167.

Bailey, Irving W.: Reversionary Characters of Traumatic Oak Woods. Bot. Gaz., Vol. L, No. 5, Nov. 1910, pp. 374–380.

Groom, Percy: The Evolution of the Annual Ring and Medullary Rays of Quercus. Annals of Botany, Vol. XXV, Oct. 1911, pp. 983–1004.

ABROMEIT, JOHANNES: Ueber die Anatomie des Eichenholzes. Berlin, 1884.

[31]*Quercus alba:*

GREELEY, W. B., AND ASHE, W. W.: White Oak in the Southern Appalachians. Cir. 105, U. S. Forest Service, 1907.

[32]*Quercus prinus:*

FOSTER, H. D., AND ASHE, W. W.: Chestnut Oak in the Southern Appalachians. Cir. 135, U. S. Forest Service, 1908.

[33]*Catalpa speciosa:*

HALL, WILLIAM L.: The Hardy Catalpa. Bul. 37, U. S. Bu. Forestry, 1902.

RECORD, SAMUEL J.: The Hardy Catalpa. Pub. 22, Dept. of Botany, Wabash College, Crawfordsville, Ind., 1906.

ROBERTS, H. F.: The Hardy Catalpa. Bul. No. 108, Exp. Sta., Kansas State Agri. Coll., Manhattan, Kans., 1902.

[34]*Sassafras sassafras:*

KNOBLAUCH, E.: Anatomie des Holzes der Laurineen. Flora, 1888, Nos. 22–26, pp. 339–400. See also Bot. Centralblatt, Vol. XXXIX, p. 125.

[35]*Toxylon pomiferum:*

MAXWELL, HU.: Utilization of Osage Orange. Pub. by Farm Wagon Dept., Natl. Implement and Vehicle Assn., U. S. A., 1911.

SUDWORTH, GEORGE B., AND MELL, CLAYTON D.: Fustic Wood: Its Substitutes and Adulterants. Cir. 184, U. S. Forest Service, 1911, pp. 8–9.

[36]*Robinia pseudacacia:*

JAENSCH, TH.: Zur Anatomie einiger Leguminosenhölzer. Ber. d. deutschen Bot. Gesellschaft, Vol. II, Berlin, 1884.

SAUPE, K. ALWIN: Der Anatomische Bau des Holzes der Leguminosen und sein Systematischenwerth. Regensburg, 1887.

[37]*Diospyros virginiana:*

MOLISCH, H.: Vergleichende Anatomie des Holzes der Ebenaceen und ihrer Verwandten. Sitzb. der kaiserlichen Akademie der Wissenschaft, Vol. LXXX, Part I, Wien, 1879.

[38]*Hickory:*

BOISEN, ANTON T., AND NEWLIN, J. A.: The Commercial Hickories. Bul. 80, U. S. Forest Service, 1910.

HATCH, CHARLES F.: Manufacture and Utilization of Hickory, 1911. Cir. 187, U. S. Forest Service, 1911.

[39]*Evergreen Oak Group:*

BAILEY, IRVING W.: Notes on the Wood Structure of the Betulaceæ and Fagaceæ. For. Quarterly, Vol. VIII, No. 2, 1910.

[40]*Quercus densiflora:*

JEPSON, WILLIS LINN, AND BETTS, H. S.: California Tanbark Oak. Bul. 75, U. S. Forest Service, 1911.

[41]*Swietenia mahagoni:*

SUDWORTH, GEORGE B., AND MELL, CLAYTON D.: "Colombian Mahogany"; Its Characteristics and Its Use as a Substitute for True Mahogany. Cir. 185, U. S. Forest Service, 1911.

BUSCH, P.: The Commercial Mahoganies. Tropenpflanzen, Vol. XV, No. 9, 1911, pp. 479–493.

[42]*Eucalyptus globulus:*

BETTS, H. S., AND SMITH, C. STOWELL: Utilization of California Eucalypts. Cir. 179, U. S. Forest Service, 1910.

[43]*Walnut:*

SUDWORTH, GEORGE B., AND MELL, CLAYTON D.: Identification of North American Walnut Woods. Bul. 120, U. S. Forest Service, (in press).

[44]*Carpinus caroliniana:*

BAILEY, IRVING W.: Notes on the Wood Structure of the Betulaceæ and Fagaceæ. For. Quarterly, Vol. VIII, No. 2, 1910.

[45]*Alnus oregona:*

BAILEY, IRVING W.: The Relation of the Leaf-Trace to the Formation of Compound Rays in the Lower Dicotyledons. Annals of Botany, Vol. XXV, Jan. 1911.

OAKLEAF, HOWARD B.: The Wood-Using Industries of Oregon. Pub. of Oregon Conservation Assn., 1911, pp. 38–39, 41.

[46]*Maple:*

HOLDEN, RUTH: Some Features in the Anatomy of the Sapindales. Bot. Gaz., Vol. LIII, Jan. 1912, pp. 50–57.

[47]*Basswood:*

RECORD, SAMUEL J.: Tier-like Arrangement of the Elements of Certain Woods. Science, Vol. XXXIV, Jan. 12, 1912, pp. 75–77.

[48]*Liriodendron tulipifera:*

GROPPLER, ROBERT: Vergleichende Anatomie des Holzes der Magnoliaceen. Stuttgart, 1894. See also Bot. Centralblatt, Vol. LX, p. 373.

[49]*Liquidambar styraciflua:*

CHITTENDEN, ALFRED K., AND HATT, W. KENDRICK: The Red Gum. Bul. 58, U. S. Bu. Forestry, 1905.

[50]*Betula papyrifera:*

DANA, S. T.: Paper Birch in the Northeast. Cir. 163, U. S. Forest Service, 1909.

[51]*Nyssa aquatica:*

HOLROYD, H. B.: The Utilization of Tupelo. Cir. 40, U. S. Forest Service, 1906.

SUDWORTH, GEORGE B., AND MELL, CLAYTON D.: Distinguishing Characteristics of North American Gumwoods. Bul. 103, U. S. Forest Service, 1911.

VON SCHRENCK, HERMANN: Tupelo. Southern Lumberman, Anniversary ed., 1907.

[52]*Æsculus octandra:*

RECORD, SAMUEL J.: Tier-like Arrangement of the Elements of Certain Woods. Science, Vol. XXXIV, Jan. 12, 1912, pp. 75–77.

[53]*Salix nigra:*

PENHALLOW, D. P.: A Systematic Study of the Salicaceæ. Am. Naturalist, Vol. XXXIX, No. 464, Aug. 1905.

HOLDEN, RUTH: Reduction and Reversion in the North American Salicales. Annals of Botany, Vol. XXVI, Jan. 1912, pp. 165–173.

[54]*Populus tremuloides:*

WEIGLE, W. G., AND FROTHINGHAM, E. H.: The Aspens: Their Growth and Management. Bul. 93, U. S. Forest Service, 1911.

BURGERSTEIN, A.: Diagnostische Merkmale der Markstrahlen von Populus und Salix, Ber. d. Deutschen botanischen Gesellschaft, Vol. XXIX, No. 10, 1911.

BRETON-BONNARD, L.: Le Peuplier. Paris, Lucien Laveur, 1903.

# INDEX

# DESCRIPTION OF PLATES

**All photomicrographs (except frontispiece) show magnification of 50 diameters.**

PLATE I.

## DESCRIPTION OF PLATE I.

Map of the United States showing Natural Forest Regions.


Map of the United States showing Natural Forest Regions. (U. S. Forest Service.)

PLATE II.

## DESCRIPTION OF PLATE II.

FIG. 1.—*Taxodium distichum* (bald cypress): cross section through portions of two growth rings. Several resin cells are visible near the lower edge.

FIG. 2.—*Tsuga canadensis* (eastern hemlock): cross section. Note decided contrast between early and late wood.

FIG. 3.—*Juniperus virginiana* (red cedar): cross section through median portion of growth ring showing zonate arrangement of resin cells.

FIG. 4.—The same: cross section showing very thin late wood; also doubling of the late wood, producing "false ring." Note small size of tracheids.

FIG. 5.—*Quercus alba* (white oak): cross section showing small pores with thin walls and angular outlines and in broad band; large pores with tyloses.

FIG. 6.—*Quercus rubra* (red oak): cross section showing small pores with thick walls and circular outlines, and in narrow band; large pores without tyloses.

PLATE II.

Fig. 1

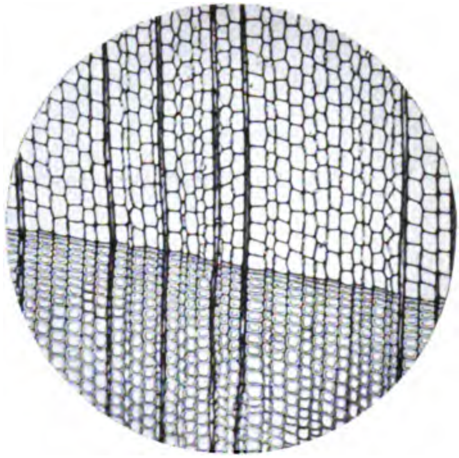

Fig. 2

Fig. 3

Fig. 4

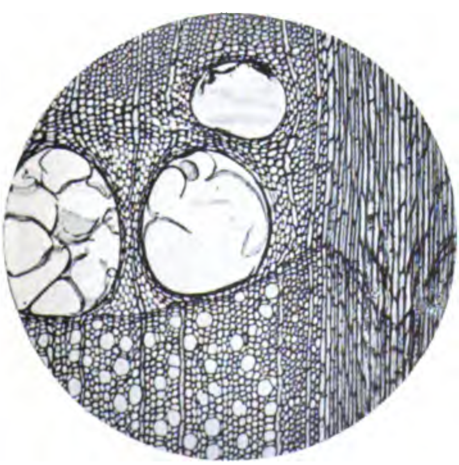

Fig. 5

Fig. 6

PLATE III.

## DESCRIPTION OF PLATE III.

FIG. 1.—*Quercus alba* (white oak): tangential section showing end of large ray and numerous small uniseriate rays, separated by wood fibres, and occasional wood-parenchyma fibres.

FIG. 2.—*Ulmus americana* (American elm): cross section showing the largest pores in a single row, the small pores in wavy tangential bands.

FIG. 3.—*Robinia pseudacacia* (black locust): cross section showing arrangement of pores and parenchyma, and very dense wood fibres in late wood; pores in early plugged with tyloses and separated by abundant wood parenchyma and tracheids.

FIG. 4.—*Toxylon pomiferum* (Osage orange): radial section showing tyloses in vessels; wood-parenchyma fibres, tracheids and dense wood fibres; and heterogeneous ray.

FIG. 5.—*Gymnocladus dioicus* (Kentucky coffee tree): cross section showing comparatively large, thin-walled pores in late wood.

FIG. 6.—*Gleditsia triacanthos* (honey locust): cross section showing minute, thick-walled pores in late wood. Growth ring limited by rather wide zone of wood parenchyma.

## PLATE III.

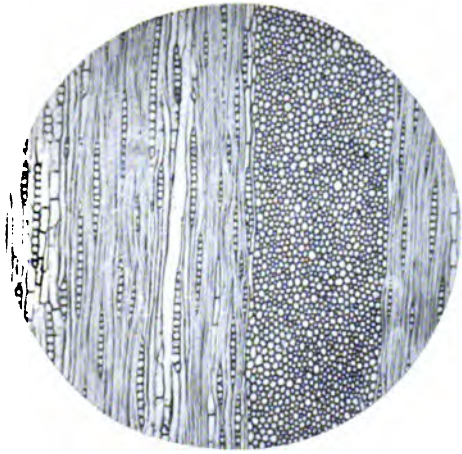

FIG. 1

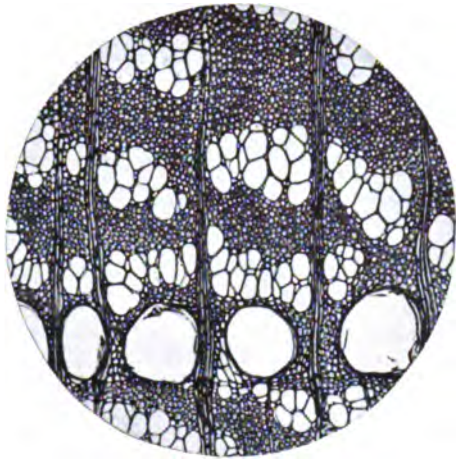

FIG. 2

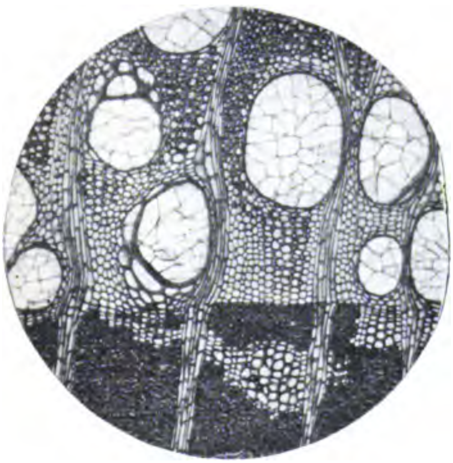

FIG. 3

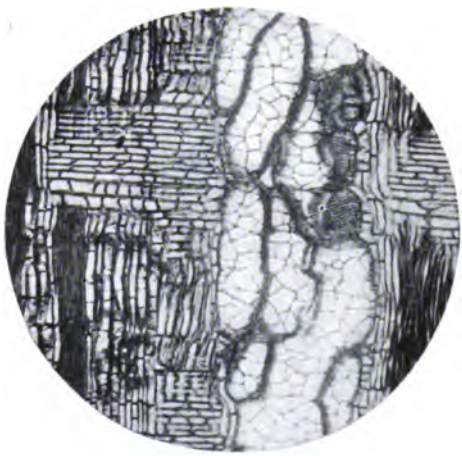

FIG. 4

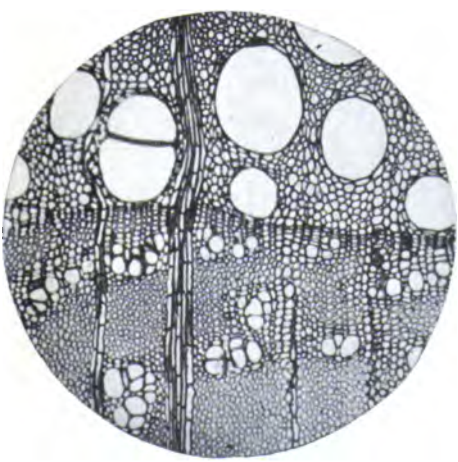

FIG. 5

FIG. 6

## PLATE IV.

## DESCRIPTION OF PLATE IV.

FIG. 1.—*Hicoria ovata* (shagbark hickory): cross section showing very thick-walled wood fibres and distinct tangential lines of wood parenchyma; large pores with tyloses.

FIG. 2.—*Diospyros virginiana* (persimmon): cross section showing rather indistinct tangential lines of wood parenchyma; pores without tyloses.

FIG. 3.—*Hicoria pecan* (pecan hickory): tangential section showing very irregular rays, three large calcium-oxalate crystals, and numerous wood-parenchyma fibres.

FIG. 4.—*Diospyros virginiana:* tangential section showing fairly uniform rays in storied arrangement. Crystals visible, but very small.

FIG. 5.—The same: radial section showing vessel segments, heterogeneous rays, wood-parenchyma fibres, and wood fibres in tier-like arrangement.

FIG. 6.—*Juglans nigra* (black walnut): radial section showing rays, large vessel with tyloses, wood-parenchyma fibres, chambered-parenchyma fibres with crystals, and wood fibres.

PLATE IV

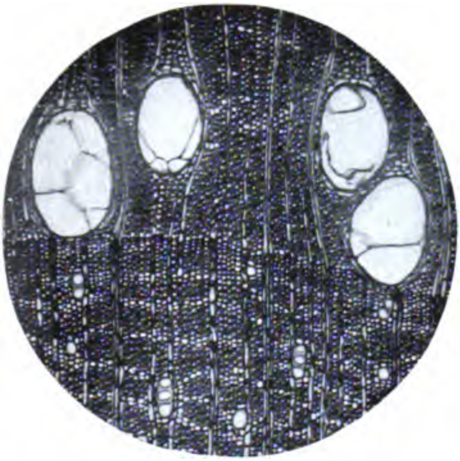

FIG. 1

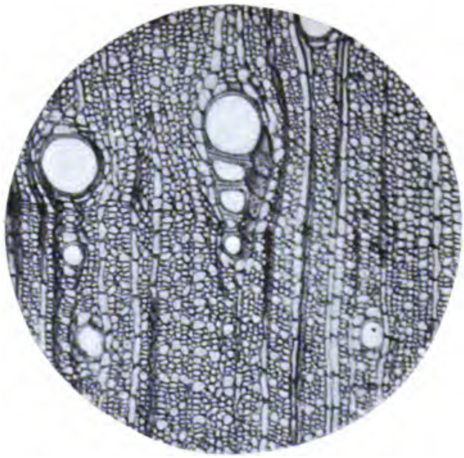

FIG. 2

FIG. 3

FIG. 4

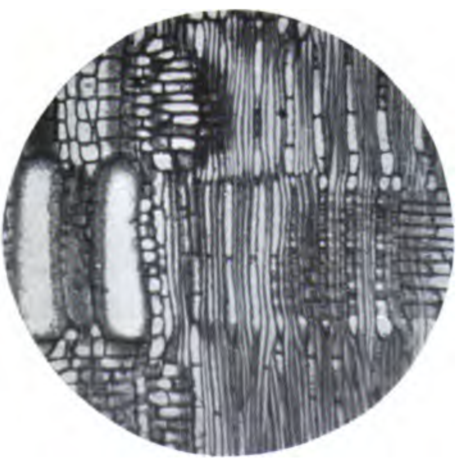

FIG. 5

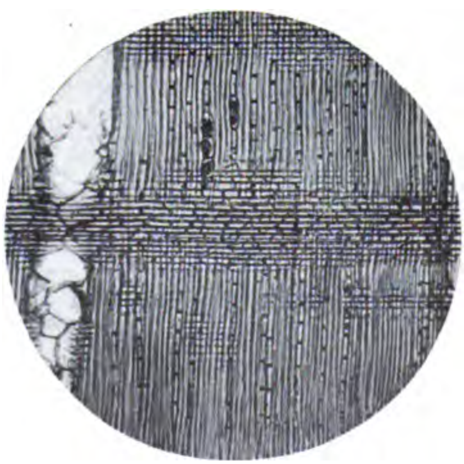

FIG. 6

PLATE V.

## DESCRIPTION OF PLATE V.

FIG. 1.—*Morus rubra* (red mulberry): cross section showing arrangement of pores in late wood, width of rays, and presence of tyloses in large pores.

FIG. 2.—*Fraxinus nigra* (black ash): cross section showing isolated pores in late wood not joined tangentially by wood parenchyma. Outer margin of growth ring composed of thin layer of wood parenchyma.

FIG. 3.—*Alnus oregona* (red alder): cross section showing aggregate ray and distribution of pores.

FIG. 4.—The same: tangential section showing aggregate ray, intermediate uniseriate rays, vessels, wood fibres, and wood-parenchyma fibres.

FIG. 5.—*Betula lenta* (sweet or black birch): cross section showing size and distribution of pores and width of rays. Note wood-parenchyma fibres, isolated or in short tangential lines.

FIG. 6.—*Ostrya virginiana* (hornbeam): cross section showing size and arrangement of pores and distribution of wood-parenchyma fibres in inconspicuous tangential lines.

PLATE V

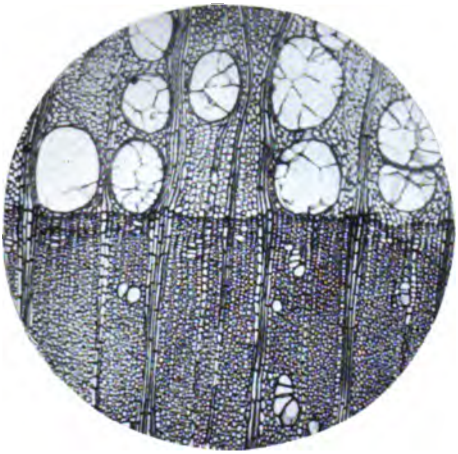

FIG. 1

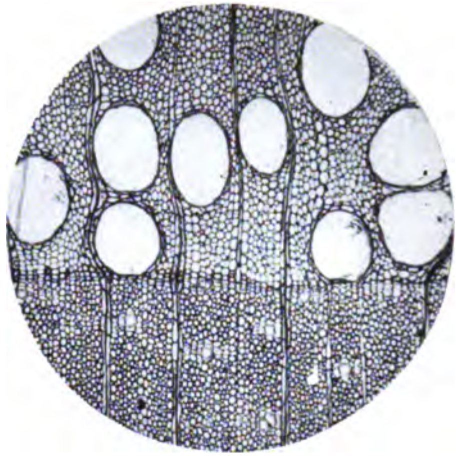

FIG. 2

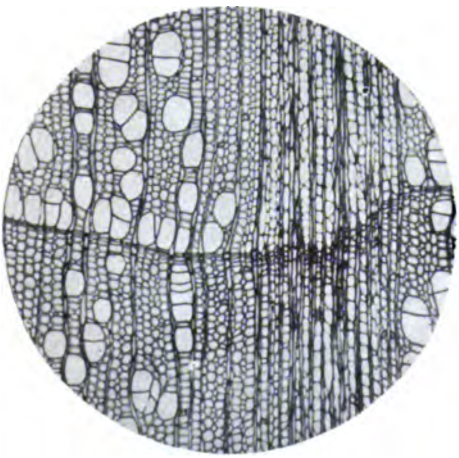

FIG. 3

FIG. 4

FIG. 5

FIG. 6

PLATE VI.